PSYCHO-RHEOLOGY IN THE BREAD-MAKING INDUSTRY

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The importance of the psychological aspects in the problem of the judging of flour strength has already been pointed out by Katz (1937). In many parts of the world, the quality of a flour is still assessed by a baking test, the conditions of which are defined by the subjective judgments of the baker, and even where the control is entirely mechanical, the final criterion of quality is the satisfaction or dissatisfaction which the baker expresses, in relation to his own standards and interpretation of public taste. This taste varies widely in different countries, and even in different parts of the same country, and there is also a large personal factor differentiating even the best of bakers within quite a small geographical area.

Katz has pointed out that the physical factors judged by feel are not necessarily the same as those chosen by the physicist in order to classify his data. He points out that "the psychological properties, *e.g.* body and spring, do not correspond to the physical properties of viscosity, elasticity, etc., but are rather the result of a complicated cooperation of the different senses of the skin, the muscles, the sinews, and the joints." It is of interest in many industries, and perhaps most of all in the bread-making and dairy industries, to study the nature of the physical properties which can be assessed by touch, with what order of accuracy these can be determined, and in what manner the experienced technician is at an advantage by comparison with the ordinary citizen. It is with these three problems that the present paper is intended to deal.

Katz quotes a letter from the present writer, as follows: "It seems as though differences in certain physical properties are much more easily observed by feel than is the case with others. For example, we suspect that the hand is comparatively sensitive to changes in elasticity modulus, but insensitive to changes in viscosity."

It therefore seemed advisable to find out what percentage differences could be detected in the viscosity of a series of true fluids, and in the compression moduli of elastic solids.   Scott Blair and Coppen (1939) have described experiments on about a dozen subjects having widely differing education and technological experience, and it appears that the smallest differences in viscosity which can be distinguished significantly more often than can be accounted for by chance, vary only a little as between different subjects.   Bakers were not tested, but experienced cheese graders showed no more sensitivity than science graduates, graduates in arts, or subjects who had had only very simple education.

It is difficult to decide on the best single criterion from a batch of data such as these, but, merely for convenience, we will define the threshold for viscosity ($\Theta\eta$) as the percentage change in viscosity which can be correctly given 80 times out of a hundred.   The mean value of $\Theta\eta$ under the conditions of our experiments, using Californian bitumen diluted with oil, and having a viscosity of the order of 10^6 poises (*i.e.* a hundred million times that of water) is 30%.   The viscosities of the bitumen samples were determined by the method of rheograms first described by Schofield and Scott Blair (1932, 1933, 1933a, 1937) for use for flour doughs.

A similar experiment was carried out with rubber cylinders containing different amounts of "filler" which behaved as approximately elastic solids differing slightly in compression moduli, the compression moduli being of the order of 1.5×10^7 dynes/cm^2.   The psycho-physical technique is being described elsewhere but the results will be of some interest to cereal chemists.

Unlike viscosity, the "threshold" for compression modulus ($\Theta\kappa$) is by no means the same for different subjects, though again the skilled craftsman is at no advantage.   Some subjects have decidedly lower $\Theta\kappa$ values than others.   Although our best two subjects were both routine analysts, the work is still at too early a stage for it to be possible to draw definite positive conclusions as to the relationship between education or training, on the one hand, and sensitivity to changes in elasticity moduli, but the negative conclusion that the experienced craftsman is not above the average is definite.   It is also found that the threshold for compression modulus is only about one-third of that for viscosity.   This means that, as suggested many years ago in my letter to Katz, elastic properties are more accurately differentiated than viscous properties.   Perhaps this is true because it is easier to judge firmness statically in elastic systems.   If a given stress is maintained, the deformation remains constant as long as the subject likes, whereas for a viscous material, an extra dimension is introduced,

and judgments must be made dynamically.   If stress is kept constant, the sample keeps on deforming at a constant rate.   The question is, however, still not fully understood.

Flour dough, and for that matter cheese, for which these experiments were primarily designed, are not true fluids like some of the bitumens, nor elastic solids like rubber (even though the consumer may occasionally doubt the last statement in the case of cheese!). They are intermediate in properties between the two, and Schofield and Scott Blair (1932, 1933, 1933a, 1937) have proposed equations containing an elastic and a viscous term (Hookian and Newtonian terms) to account for the experimental facts.   Other workers, notably Bohn and Bailey (1936, 1936a), have also worked on similar lines.

Purely from the rheological point of view, this type of treatment is both practically useful and theoretically sound, but, as Katz has pointed out, the physical composites judged by technicians when handling a material like dough are by no means necessarily the same as those usual to the physicist.   The conception of viscosity was evolved to explain the behavior of a material like water, which flows just twice as fast when pushed twice as hard; and that of elasticity was introduced by Hooke in his famous law, *ut tensio ut vis*, which is so nearly true for the recoverable deformations of metals and the like. When a baker judges "firmness" or "spring," he does not, in fact, divide his sensations into viscous and elastic parts, but forms a judgment based on the general behavior of the dough when handled. These facts suggest the need for a new line of approach in the rheological treatment of data for materials like dough.   The author is in process of developing such a treatment, based on the following general considerations.

If a subject is asked to say which is the firmer of two viscous bitumens, he interprets "firmness" in terms of viscosity, whereas if he is comparing rubbers, he judges entirely by compression modulus. When given a bitumen to compare with a rubber, he is, in effect, trying to compare properties which have different dimensions.   It is as if he were asked "Which is the greater, an hour or an elephant?" Most subjects do not realize this but make some kind of mental synthesis, and if the two stimuli differ greatly in terms of their own absolute standards, they show no hesitation in giving an opinion.   Thus, to take the extreme case quoted, most non-scientific people at least would say that an elephant is bigger than a second, but might hesitate when asked to consider an hour or a day.   In the case of rubber having a compression modulus of about 1.5×10^7 cg. units and a bitumen of viscosity about 5×10^6 cg. units, the subject will generally give the bitumen as the firmer if he compresses for only half a second, but the rubber, if allowed to compress for four seconds.

Subjects (including, of course, bakers) judge firmness by some entity of inconstant dimensions, the dimensions depending on "spring," and this suggests a line of approach on the rheological side. In a viscous material, the shearing stress is proportional to the strain multiplied by the time of application taken to the power of minus one. In an elastic solid, the time does not enter, or we may say that its exponent is zero. In both cases the constant of proportionality expresses firmness in the subjective sphere. May we not assume a similar state of affairs in a material like dough?

In such a case the dimensions of "firmness" will depend on the exponent of time. When this is zero, we have an elastic solid, and firmness becomes its modulus, whereas at the other extreme, the exponent being -1, the material is a true fluid, and its firmness is judged by viscosity. The exponent is, of course, a measure of "spring." The more "lively" the dough, the nearer the exponent approaches zero; the more "dead" the dough, the more closely it approximates to -1.

The connexion with the actual facts of subjective judging is so good that one does not feel disposed to allow the dimensional difficulties to stand in the way of the formulation of an equation along these lines, especially since a logarithmic form of equation will eliminate the difficulty at least formally. Such an equation will be developed elsewhere.

The last problem to be discussed is the nature of the advantage (if any) which the skilled craftsman has over the ordinary citizen in judging the rheological properties of materials.

From the experiments already described, it seems unlikely that there is any advantage, either inborn or developed, in the direct capacity to judge small rheological differences and one is left with two further possibilities.

It would be only natural to expect that, even if the brains of two subjects received the same impulses as the results of a test, the brain which was already armed with a wide knowledge and experience of the bread-making industry would be able to use the information obtained more effectively than would that of a person altogether ignorant of the subject. But there is also another way in which experience may help. In comparing the firmness of two materials, for example, we have seen that the length of time may drastically influence the judgment. If the materials are doughs, which show all the complex phenomena of work-hardening, structural viscosity, and elastic hysteresis, the exact conditions of stress and deformation will also be very important. If the comparison is not made directly, but after a considerable interval of time, two factors become important: (1) the

capacity to recognize rheological criteria previously met with and (2) the capacity to reproduce the movements of the hand used to make the test. It may well be that one type of movement is better than another. Is the expert using the best method, or is he using the same method each time, but not the best? By studying his movements we may hope to help him in this respect.

Head (1920) suggests that the sequence of any series of movements is controlled by mental pictures [1] of the postures involved in the movement, so that each posture must be considered in relation to the movement as a whole, thus introducing a kind of hysteresis. The existence of these mental pictures, which are called "schemata," enable us to perform without conscious thinking all the complex movements of everyday life. These ideas have been much developed by Bartlett (1932) and he has further suggested that they may be in some manner applicable to the problem of the psychological basis of craftsmanship such as we have been discussing.

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[1] One is not conscious of the presence of these mental pictures.

A STANDARDIZED WOHLGEMUTH PROCEDURE FOR ALPHA-AMYLASE ACTIVITY [1]

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Since its adoption as a quantitative procedure by Wohlgemuth (1908) the amylolytic destruction of the ability of starch to give its characteristic blue color with iodine has been extensively used in measuring a certain type of diastatic activity. The hydrolytic action measured by this method has been characterized as dextrinization. The amylase component of malt which can readily bring about this change has been designated the dextrinogenic amylase, or more recently alpha-amylase. Based on the hypothesis that beta-amylase, the saccharogenic amylase of malt, plays little if any role in starch dextrinization, the rate of dextrinization as measured by the Wohlgemuth method has been generally accepted as exclusively a measure of alpha-amylase activity.

Ohlsson (1926, 1930) recognized that beta-amylase activity must be considered in the early color changes of the Wohlgemuth method but believed its action insignificant in the determination of his "x-values." By "x-value" he refers to dextrinization as measured at a point just preceding the final "colorless" end point with iodine. Holmberg (1933) recognized that some of the color change is influenced by the presence of beta-amylase. The roughly additive function of a mixture of alpha- and beta-amylases in starch saccharification was pointed out by Ohlsson (1926) and again by Freeman and Hopkins (1936). Blom, Bak, and Braae (1937) demonstrated the overlapping effects of alpha- and beta-amylases in starch dextrinization as well as saccharification. Finally Hanes and Cattle (1938) in an investigation of starch hydrolysis by mixtures of alpha- and beta-amylases found that "the rate of destruction of the iodine coloring property is by no means an exclusive function of the amount of the alpha-component."

If indeed beta-amylase strongly affects rate of dextrinization, and if the degree of effect varies with the quantity of beta-amylase present, it is obviously essential to eliminate or control this variable in any procedure intended for the exclusive and trustworthy measurement of alpha-amylase. An examination of possibilities in this direction has been undertaken, with results and conclusions as herewith reported.

The End Point

In the Wohlgemuth type of method dextrinogenic activity is measured in terms of the digestion time required to produce a color change denoting complete dextrinization of the starch. Since the operator has a choice of several shades and types of color within the region of this end point it is apparent that the selection of a specific type and depth of color is an essential feature in any approach to a standardized procedure.

Hanes (1937) and Hanes and Cattle (1938) have presented evidence indicating that the ultimate in dextrinization is reached at the achroic point, *i.e.*, the point at which no additional color is imparted to the iodine when a sample of the digestion mixture is added. Ohlsson (1930) has likewise indicated a preference for this end point. On the other hand numerous investigators have used as an end point some color intermediate between blue and "colorless," such as red or orange.

In the routine procedure of visual color comparisons the achroic point is difficult to determine. A much more suitable end point is one intermediate between immediately preceding and succeeding colors. As a color standard it should be constant, easily reproducible, and readily distinguishable when one is following a prescribed technique. Obviously the stage of dextrinization which the selected end point represents must in turn be capable of giving linear differentiation among varying amounts of alpha-amylase. These requirements are satisfied by the red-brown color produced by the combination, in definite proportions, of solutions of iodine and Merck's "Reagent" dextrin. The details of preparation are given under "Reagents."

Beta-Amylase and Dextrinization

Numerous investigations have shown that the action of beta-amylase alone on soluble starch does not cause the starch to lose its iodine coloring property; in fact the dextrinizing power of alpha-amylase has served as one means of differentiating the two amylases. The joint action of alpha- and beta-amylase in dextrinization is not clearly understood. However, in a recent investigation by Hanes and Cattle (1938) it was noted that the addition of beta-amylase to a starch-alpha-amylase mixture reduced the time required to reach the achroic point from 140 to 55 minutes.

Figure 1 presents typical data indicating our own results on the combined action of alpha- and beta-amylase. Curve A shows the effect of superimposing progressively increasing quantities of beta-amylase upon equal portions of malt-starch digestion mixtures, all of the amylase components being added simultaneously in each instance. Constant total volumes were maintained by the addition of appropriate

quantities of water.   In this series of trials the time required to reach
the red-brown standard-color end point was reduced from 27 to 11.5
minutes by the addition of 2 cc. of beta-amylase solution.   Especially
noteworthy is the fact that the further addition of increments of beta-
amylase beyond 2 cc. does not result in any further decrease in
dextrinizing time.   This held true for increments up to at least 5 cc.,
or more than twice the smallest volume of beta-amylase required to
give minimum time.

Curve B of Figure 1 illustrates the effect of increments of beta-
amylase on the speed of dextrinization, using purified alpha-amylase
instead of malt.   In this instance an excess of beta-amylase decreased
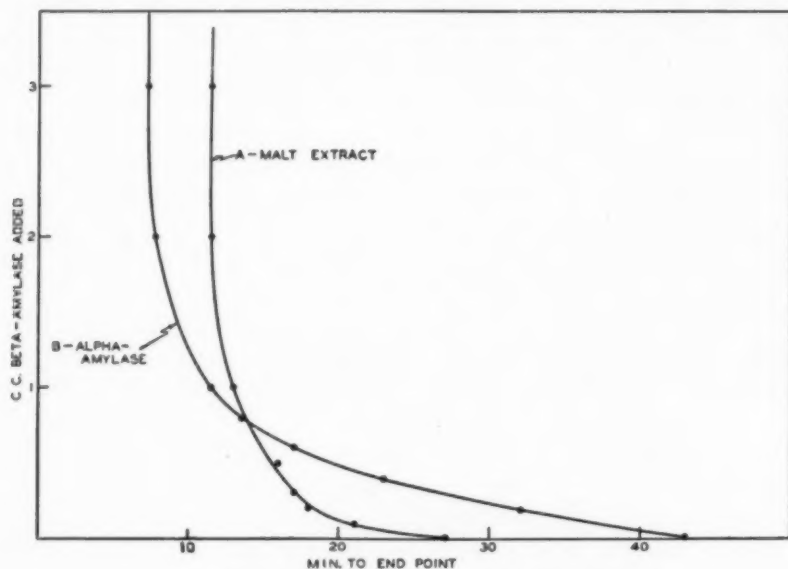
Fig. 1. Effect of beta-amylase upon rate of dextrinization.

the dextrinization time from 43 minutes to 7.3 minutes; *i.e.*, the
reaction speed was increased nearly six times.   The alpha-amylase
used in this and other experiments reported was prepared from malt by
the Ohlsson (1930) technique.   It had insignificant beta-amylase
activity and apparently contained about 85% of the alpha-amylase
originally present in the malt extract from which it was prepared.

Considerable experimental evidence has been obtained in this
laboratory demonstrating that the incorporation of beta-amylase in the
buffered starch sometime previously to the use of this treated starch
for alpha-amylase determinations materially reduces the minimum
addition of beta-amylase necessary to eliminate the variable effect of
beta-amylase present in the malt extract.   In the experiments repre-

sented by Curve B of Figure 1 the beta-amylase increments were present in 100 cc. of starch solution for one hour preceding the run. At the end of the hour 20-cc. aliquots were removed and a constant amount of alpha-amylase in 10 cc. added for determination of dextrinization rates.   It is apparent that for this particular preparation of beta-amylase 3 cc. in 100 cc. of 2% starch is adequate when added one hour before alpha-amylase determinations are to be made. Additional increments up to 5 cc. showed no further effect.   For this same sample of beta-amylase when beta- and alpha-amylase were added simultaneously to 20 cc. of 2% starch at the beginning of the run, 5 cc. was necessary to give minimal time.   Further it was found that 5 cc. of this same preparation was sufficient for *500 cc.* of 2% buffered starch, provided it was added *24 hours* before the addition of the dextrinizing component; *i.e.*, the beta-amylase was 25 times as effective when added a day before use.

This behavior of beta-amylase in influencing rate of dextrinization suggests the manner of its utilization in the determination of relative alpha-malt-amylase activity.   When applied to malt, the Wohlgemuth method simply measures the total dextrinizing power resulting from the combined activities of the alpha- and beta-amylase components, and indeed this may be all that is needed for many if not for most practical requirements.   If however one wishes to measure alpha-amylase effect *alone*, it is necessary to eliminate variability in beta-amylase activity as an influencing factor.   This, seemingly, can be most conveniently accomplished by providing conditions which permit beta-amylase to exert its *maximum* effect.

It has been proposed by Ohlsson (1930) that the time to "colorless" (his "x-value") gives a measure of alpha-amylase activity even in the presence of beta-amylase.   Table I illustrates the effect of beta-amylase increments on the time required to reach the achroic point.

TABLE I

EFFECT OF BETA-AMYLASE UPON RATE OF DEXTRINIZATION BY ALPHA-AMYLASE

Beta-amylase addition	Time to end point	
	Red-brown	Colorless
cc.	*Min.*	*Min.*
0.0	43.0	103
0.2	32.0	74
0.4	23.0	57
0.6	17.0	41
0.8	13.5	37
1.0	11.5	34
2.0	7.8	35
3.0	7.3	34
4.0	7.3	32
5.0	7.3	33

The beta-amylase was added one hour before the run and represents the amount in 100 cc. of 2% buffered starch solution. A constant quantity of alpha-amylase was used throughout. The data for "time to red-brown" has already been reported in Curve B of Figure 1 and is repeated here for comparison. It is apparent from Table I that increments of beta-amylase have the same general influence whether a red-brown or colorless end point is used. As might be anticipated, somewhat less beta-amylase is necessary to give maximum effect where the reaction is carried to colorless than is the case when the red-brown end point is used. This is probably attributable to the fact that the time interval for dextrinization to proceed to the achroic point is longer than that required to reach the "red-brown" stage.

It appears that in order to measure relative alpha-amylase activity precisely, an excess of beta-amylase should be added no matter what end point is chosen. Exceptions would occur only where all the solutions being compared have either no beta-amylase, an excess already present, or exactly equal amounts below the excess level. The possibility of encountering any of these conditions is so uncertain that it is highly advisable to so supplement the beta-amylase as to insure an excess. The presence of relatively large amounts of beta-amylase in the test solution would naturally decrease the supplementary requirement. However a routine method necessitates the uniform addition of amounts sufficient for all conditions.

From the results presented the inference might be drawn that the sole role of beta-amylase is rapidly to degrade the starch to alpha-amylodextrin and maltose. If this were true then increments of beta-amylase should have no influence on the dextrinizing action of alpha-amylase on alpha-amylodextrin itself. However we have found that added beta-amylase does shorten the time of further dextrinization of alpha-amylodextrin. For example in the action of a malt extract of relatively low beta-amylase content on one preparation of alpha-amylodextrin the addition of an excess of beta-amylase decreased the time of dextrinization from 14.4 minutes to 11.6. The necessary minimum addition of beta-amylase is considerably smaller than when starch is used as a substrate. In the specific case noted the addition of 1 cc. of beta-amylase solution was more than adequate, whereas with the same malt extract acting on *starch*, 3 cc. represented a minimum.

The alpha-amylodextrin used in the above experiment was prepared in the usual manner by the action of beta-amylase on boiled potato starch. After completion of this reaction the digest was boiled to inactivate the enzyme and the alpha-amylodextrin then precipitated with alcohol. A solution of the product gave a red-violet color with iodine and was almost completely resistant to further hydrolysis by

beta-amylase.   In fact with the same relative proportions as used in the alpha-amylase determination beta-amylase alone showed no measurable saccharification of the alpha-amylodextrin after 10 minutes of action and only a slight amount after 60 minutes.

Method of Expressing and Recording Results

Most workers, in accordance with the suggestion of Wohlgemuth (1908), have expressed dextrinization as the number of cc. of starch solution dextrinized by 1 cc. of enzyme solution in one hour at a specified temperature.   In whatever form the results are recorded the situation demands a linear relationship between the quantity of alpha-amylase present and the time of dextrinization.   The data recorded in Figure 2 show that this relationship is characteristic of the proposed modification.   When malt equivalents are plotted against the reciprocal of the time for dextrinization a straight line results.   This is true both for an unheated malt extract and for an alpha-amylase solution prepared from malt.   In both cases the usual technique of insuring an excess of beta-amylase was followed.
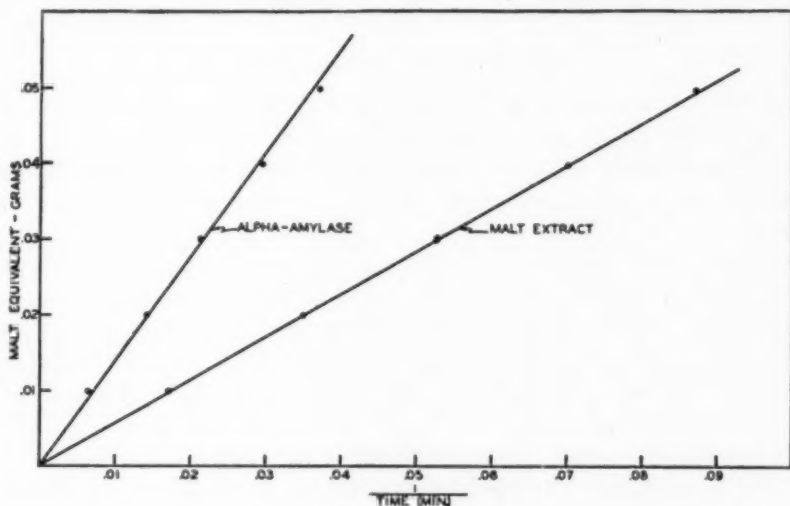
Fig. 2.   Linear relationship between alpha-amylase content and rate of dextrinization.

On the basis of this linear relationship it becomes possible to interpolate results so that a convenient method of expression may be employed with accuracy.   The original Wohlgemuth method provides for a constant quantity of starch and uniform time of dextrinization, differentiation being registered in terms of the volume of enzyme solution necessary to bring about dextrinization in constant time. The proposed modification suggests differentiation based on actual

time of dextrinization as determined for each individual sample.   It is believed that this procedure provides a maximum of flexibility and accuracy.   The deviation from familiar technique does not preclude the use of familiar terminology.   However it must be remembered that the values obtained in the alpha-amylase determination are not "Wohlgemuth values" as commonly understood.   Rather they express the relative activity of a specific component of the malt enzymes, *i.e.*, alpha-amylase.   As shown later this activity bears no constant relationship to the dextrinizing ability of the original malt extract, *i.e.*, to its Wohlgemuth value.

It is proposed then that alpha-amylase units be considered as the number of grams of soluble starch which, under the influence of an excess of beta-amylase, are dextrinized by one gram of malt in one hour at 30° C.   The volume of enzyme solution used is expressed in terms of the weight of material extracted, and the volume of 2% soluble starch dextrinized in terms of the weight of starch it represents.   The formula for calculation when using the standardized procedure then becomes:

$$\text{Alpha-amylase units} = \frac{0.4 \times 60}{\text{malt equivalent used (g.) } \times \text{ dextrinization time (min.)}}.$$

Specifications for Reagents

Stock iodine solution.—Eleven g. of iodine crystals and 22 g. of potassium iodide are made up to 500 cc. with water.

Iodine solution (A) (for standard).—Fifteen cc. of stock iodine solution and 8 g. of potassium iodide are made up to 200 cc. with water.

Dilute iodine solution (B).—Two cc. of stock iodine solution and 20 g. of potassium iodide are made up to 500 cc. with water.

Dextrin solution.—Six-tenths g. of Merck's "Reagent" dextrin (12% water content) is made up to 1,000 cc. with water.   Prepare a dextrin suspension and transfer quantitatively into boiling water.   Cool, make to volume, saturate with toluol, and store in a refrigerator.   This solution shows no signs of deterioration after one month's storage.

Buffer solution.—One hundred twenty cc. of glacial acetic acid and 164 g. of anhydrous sodium acetate are made up to 1,000 cc. with water.

Buffered alpha-amylodextrin solution.—Prepare a suspension of 10 g. of Merk's Lintner soluble starch and pour slowly into boiling water. Cool, add 25 cc. of buffer solution and 5 cc. of beta-amylase solution. Bring to 500 cc. volume, saturate with toluol, and keep at room temperature not less than 24 and preferably not more than 48 hours before use.

Beta-amylase solution.—Lack of a commercial supply of beta-amylase necessitates its preparation from biological material.   For

convenience it is desirable to avoid methods based on the selective destruction of alpha-amylase. The obvious preference involves the use of an extract of a sound ungerminated cereal grain endosperm. We have found non-diastated hard winter wheat flour to be an excellent source of beta-amylase. It is recommended that an unsupplemented hard-wheat flour of high beta-amylase activity and known freedom from alpha-amylase be used as the source material.

To prepare the beta-amylase solution extract 400 g. of hard-wheat flour with 1,000 cc. of water for several hours at room temperature. Centrifuge and filter through cotton. When saturated with toluol and stored in a refrigerator this solution retains adequate activity for months.

The proposed addition, 24 hours before use, of 1 cc. of beta-amylase solution for each 100 cc. of buffered starch solution is more than adequate to cover any normal range of variation in beta-amylase activity of soft-wheat flours. However a possibility which must be guarded against is the presence of significant alpha-amylase activity in the hard-wheat flour extract itself. Most non-malted hard-wheat flours appear to have insignificant alpha-amylase activity but occasionally one is encountered which contains an appreciable amount of the alpha component. To determine whether or not the preparation is free from alpha-amylase perhaps the simplest procedure is to compare the dextrinization times for duplicate samples of malt extract, one acting on buffered starch to which an excess of beta-amylase (5 cc. of a 2 : 5 extract) is added simultaneously with the malt extract, the other on buffered starch which has received the same amount of beta-amylase two hours previously to the determination. The presence of alpha-amylase would result in the starch treated for two hours requiring less time for dextrinization than that receiving simultaneous addition. If there is significant difference the sample of hard-wheat flour must be discarded and another one tried.

Procedure

Preparation of the standard.—Pipette 5 cc. of iodine solution (A) into a 15-cc. comparison tube.[2] Add one cc. of dextrin solution and shake. This standard should be prepared immediately before a series of determinations is to be made and serves without need of replacement for half a day.

Determination of alpha-amylase.—To 20 cc. of the buffered alpha-amylodextrin in a 50-cc. Erlenmeyer flask add 5 cc. of water and place in the 30° C. water bath. After a few minutes add 5 cc. of alpha-amylase solution to be tested. At appropriate time intervals add 1 cc.

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[2] 15-cc. graduated centrifuge tubes serve as convenient comparison tubes.

of the hydrolyzing mixture to 5 cc. of dilute iodine solution (B) in a comparison tube, shake and compare with the standard. Color comparisons are made before a lightly screened 100-watt "daylight" bulb.

During the initial stage of the reaction it is convenient to pour approximately 1 cc. of the reacting mixture into the comparison tube. As the end point is approached the addition must be made accurately by means of a pipette. It is convenient to keep a series of tubes each containing an exact volume of 5 cc. of dilute iodine solution in readiness for testing.

For accuracy and convenience it is essential that the minimum time for dextrinization be not less than 10 minutes. With malt extracts these requirements are usually satisfied by using a 5-cc. aliquot equivalent to 0.05 g. of malt. If desirable this volume may be varied. The use of a larger or smaller volume of extract necessitates appropriate changes in the volume of water added so that the final volume of the reacting mixture is always 30 cc.

From the time interval necessary for dextrinization and the weight of malt represented by the extract aliquot taken, alpha-amylase units may be easily calculated. For example if an aliquot equivalent to 0.05 g. of malt dextrinizes 20 cc. (0.4 g.) of starch in 15 minutes the alpha-amylase activity is represented by $\dfrac{0.4 \times 60}{0.05 \times 15}$ or 32 alpha-amylase units.

Application of the Standardized Procedure

The determined alpha-amylase activity of a malt will depend to some extent on the method of obtaining the extract. The conditions which we have found most suitable and convenient are as follows. Grind the dry malt sample finely in a burr mill. To one g. of the ground malt add 100 cc. of water and extract at 30° C. for one hour. At the end of the hour transfer to a centrifuge tube and centrifuge for 5 minutes. Filter the centrifugate rapidly through cotton. The extract is now ready for use.

A few trials were carried out to determine the influence of fineness of grinding and the time and temperature of extraction on the alpha-amylase activity of the extract. Within normal limits variation in fineness of grinding proved insignificant. Standardizing the time of extraction proved somewhat more important. In one instance a 60-minute extraction showed 40.0 alpha-amylase units as compared to 38.4 units for a 30-minute and 36.9 units for a 15-minute extraction. Extraction times of longer than one hour at 30° C. give slight increases in alpha-amylase activity but not large enough to justify the extra time involved. The significance of extraction temperature is well

illustrated by the data for one malt which by extraction for an hour at 30° C. showed 50.5 units of alpha-amylase activity. A duplicate sample, with the exception that it was extracted at 20° C., gave a value of 40.8 units.

A necessary precaution is that of determining the activities of the malt extracts as soon after extraction as possible. No significant loss of activity was observed over an 8-hour period but at the end of 48 hours, even when stored with toluol in a refrigerator, about 8% of the alpha-amylase activity was lost.

When the above procedure is observed duplicate malt samples may be ground, extracted, and run independently with less than 5% deviation between their measured alpha-amylase activities.

Data for the extracts from eight whole dry malts are shown in Table II. Several of these samples were supplied by the late Dr. D. A. Coleman, the remainder by the A.A.C.C. Committee on Malt Analysis. Dextrinizing and saccharifying activities of the malt extracts were determined as well as the activity attributable specifically to alpha-amylase.

TABLE II

STARCH-DEGRADING PROPERTIES OF VARIOUS MALTS

Malt	Approx. Lintner value	Saccharification		Dextrinization		Alpha-amylase		
		Starch conversion		Time to end point	Relative value	Time to end point	Relative value	Alpha-amylase units
		15 min.	60 min.					
	Degree	%	%	*Min.*		*Min.*		
A	159	56.0	74.9	22.0	100	12.3	100	39.0
B	139	51.0	73.6	23.5	94	12.1	102	39.7
C	108	38.0	73.3	32.3	68	16.5	75	29.1
D	94	37.4	73.3	30.0	73	12.5	98	38.4
E	72	30.3	71.8	33.8	65	12.8	96	37.5
F	51	21.3	65.1	70.0	31	27.5	45	17.5
G	50	18.4	59.3	54.0	41	18.0	68	26.7
H	23	13.0	41.9	81.5	27	18.5	66	26.0

All determinations were run in a comparable manner using 20 cc. of 2% buffered soluble starch, the equivalent of 0.05 g. of malt, a total volume of 30 cc., and a 30° C. temperature as the conditions for reaction. Dextrinization and saccharification as such were of course determined without the addition of any increment of beta-amylase.

The Lintner values of Table II are in some instances the averages of those reported by a number of collaborators, in others the values supplied with the sample. Saccharification is expressed as percent of starch converted to maltose in the time interval stated. Dextrinization

is reported as the time interval necessary for the unsupplemented malt
extract to reach the red-brown end point.   Alpha-amylase activity is
reported both in terms of the time necessary for the supplemented
extract to reach the end point and as alpha-amylase units.   For both
dextrinization and alpha-amylase activity relative values are given
with the results for sample A as 100.

The data shown in Table II confirm those of Blish, Sandstedt, and
Kneen (1938) in as much as there is an excellent correlation between
percent starch converted in 15 minutes and Lintner value.   There is
likewise a decided tendency for the dextrinizing activity to correlate
closely with saccharification.

Turning now to specific alpha-amylase activity it is obvious that it
does not correlate well with either saccharification or dextrinization.
The general tendency is for those malts in the upper range of Lintner
values to have a high alpha-amylase activity.   However, malts A and
D while representing a wide spread in saccharifying and dextrinizing
ability are nearly identical as regards alpha-amylase activity.   Malts
F and H are striking in their lack of parallelism.   Malt F is more
active than H both as regards saccharification and dextrinization, yet it
has a lower alpha-amylase activity.

In addition to the activities shown, the data of Table II obviously
permit conclusions regarding the beta-amylase activity of certain of
the samples.   For example the fact that malt F has a higher
saccharifying ability than malt H must be attributed to a greater
amount of the beta component; otherwise its lower alpha-amylase
content would unquestionably result in less saccharification.   Like-
wise the observed saccharification values of malts E and F do not
indicate much if any difference in their beta-amylase activities.
Assuming equal amounts of beta-amylase a difference in saccharifying
activities would be predicted solely on the basis of their alpha-amylase
content.   Thus the determination of specific alpha-amylase activity
is not only valuable as such but in addition facilitates a clearer interpre-
tation of the role of both the amylase components of malt in starch
degradation.

Summary

Wohlgemuth values as commonly determined are indicative only of
the dextrinizing power of a malt extract.   This dextrinization results
from the combined activity of alpha- and beta-amylase.   Without
modification the method therefore does not offer a means of measuring
relative alpha-amylase activity.

It was found that increasing the ratio of beta-amylase to alpha-
amylase in the starch-enzyme mixture increased the rate of dextriniza-

tion up to a point beyond which further increments of beta-amylase have essentially no effect.   The basis of a standardized technique for the quantitative measurement of alpha-amylase therefore involves the addition of sufficient supplementary beta-amylase to eliminate the variable effect of beta-amylase already present in the malt extract.

The preparation and use of an easily reproducible red-brown dextrin-iodine solution as a standard end point is described.

The linear relationship between alpha-amylase content and dextrinization time permits calculation of alpha-amylase units as the number of grams of soluble starch which, under the influence of an excess of beta-amylase, are dextrinized by one gram of malt in one hour at 30° C.

Application of the method to barley malts is discussed and the lack of parallelism between alpha-amylase activity and either saccharogenic or dextrinogenic activity of malts is demonstrated.

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A MODIFICATION OF THE WOHLGEMUTH METHOD FOR THE DETERMINATION OF ALPHA-AMYLASE AND A COMPARISON OF THIS METHOD WITH A VISCOSITY METHOD

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It is generally believed that malt diastase contains at least two active components, alpha-amylase and beta-amylase. When malt diastase acts on a starch substrate the starch is first liquefied to dextrin by alpha-amylase and the dextrin thus formed is then converted to sugar, or saccharified, by beta-amylase. This dual nature of malt diastase has been made the basis of much research and several theories are advanced to explain the nature of the components of diastase. Blom, Bak, and Braae (1937) found that the liquefaction and dextrinization of starch proceed in a parallel manner, and they conclude that both are caused by alpha-amylase. This theory is supported by Józsa and Johnston (1935). Waldschmidt-Leitz and Mayer (1935), on the other hand, believe the liquefying enzyme and the dextrinizing enzyme to be two distinct enzymes. Assuming the former theory to be correct, it is entirely feasible to estimate the degree of liquefaction of a starch substrate by measuring the degree of dextrinization and *vice versa*.

This work was undertaken with the view in mind of selecting an accurate and, at the same time, a rapid method for estimating the alpha-amylase content of malt, the method selected to be suitable for routine control analysis in the malting, brewing, and distilling laboratory. Two methods were studied, a modification of Wohlgemuth's (1908) iodine-conversion method and the viscosity method of Józsa and Gore (1930) and Józsa and Johnston (1935). The modification of Wohlgemuth's method measures the alpha-amylase activity of malt by determining the time required for the malt enzyme to liquefy a starch substrate to dextrin, the end-point being determined by comparing the iodine color of the malt-starch mixture with the iodine color of a standard dextrin solution. The Józsa and Gore (1930) and Józsa and Johnston (1935) viscosity method estimates the alpha-amylase content of malt by measuring the change in viscosity of a mixture of malt extract and specially prepared raw starch solution. The two methods, although radically different from each other in mode of operation, showed satisfactory correlation with each other,

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since each was found to vary to the same extent when tested with varying concentrations of the malt enzyme (Table I).

TABLE I

COMPARISON OF ALPHA-AMYLASE VALUES DETERMINED WITH THE MODIFIED WOHLGEMUTH METHOD AND WITH THE VISCOSITY METHOD OF JÓZSA, GORE, AND JOHNSTON

Sample	Enzyme concen- tration	Alpha-amylase value (Wohlgemuth)		Viscosity method	
		Merck's dextrin	Baker's dextrin	Starch liquefied	Liquefons per 10 cc.
				mg.	
A	Full	60.0	54.5	1986	3.259
A	Full	60.0	53.3	1991	3.282
A	Full	60.0	54.5	2031	3.456
A	Full	—	—	2031	3.456
A	Full	59.3	53.4	1904	2.929
A	Half	29.3	27.6	1096	1.024
A	Half	—	—	1103	1.033
A	Half	29.6	—	1017	0.924
A	Half	—	—	1000	0.903
Av.	Full	59.8	54.0	1989	3.276
Av.	Half	29.5	27.6	1054	0.971

Note: Sodium-chloride extraction was employed for both methods in Table I in order to obtain a true comparison of the two methods.

The modification of the Wohlgemuth method as devised by the authors combines several features of the modifications proposed by Hills and Bailey (1938) and Blish, Sandstedt, and Kneen (private communication). The method of recording the conversion values in terms of cc. of 2% starch solution liquefied is, in essence, the same as the method used by Hills and Bailey. The temperature of reaction, the use of a standard dextrin tube for color comparison, and the method of arriving at the end-point were derived from a tentative method submitted to the authors (private communication) by Blish, Sandstedt, and Kneen. The following is an outline of the authors' modification of the Wohlgemuth method:

Reagents

Stock iodine solution: 11 g. iodine crystals (C.P.), 22 g. KI (C.P.), made up to 500 cc. with distilled water.

Dilute iodine solution: 2 cc. of stock iodine solution and 20 g. KI made up to 500 cc. with distilled water. (Made up fresh daily while malt is being extracted.)

Standard dextrin solution: A saturated solution of dextrin is made up as follows: 2 g. of dextrin is shaken with 100 cc. of water at 20°C.

and allowed to settle for one hour, maintaining the temperature at 20°C. throughout.   One cc. of the clear supernatant liquid is pipetted into 5 cc. of dilute iodine solution in a ¼-inch test tube to make up the standard dextrin tube for color comparison.   Baker's dextrin gives results approximately 2 minutes higher than Merck's dextrin in the 20 minute conversion range (Table I).

Acetate buffer solution: 68 g. sodium acetate ($CH_3COONa \cdot 3H_2O$) dissolved in 500 cc. of N acetic acid and the solution made up to one liter with distilled water.

Starch solution: 10 g. of Lintner soluble starch (dry basis) dissolved in water according to the method prescribed for the standard method of diastatic power determination (A.S.B.C.), 10 cc. of acetate buffer added and the whole made up to 500 cc. with distilled water.

Procedure

Twenty-five grams of finely ground malt is extracted with 500 cc. of distilled water at 20°C. and filtered according to the standard method for the determination of diastatic power (A.S.B.C.).

Ten cc. of the filtered extract is diluted to 100 cc.

Twenty cc. of 2% Lintner soluble starch solution is pipetted into a 250-cc. electrolytic beaker and placed in a constant-temperature water bath at 30°C.

During the extraction period 5-cc. portions of dilute iodine solution are pipetted into each of 18 (¼-inch) test tubes.

Ten cc. of the diluted malt extract, at 30° C., is added to the 20 cc. of 2% starch solution and mixed thoroughly.   Timing is started with a stop watch the instant the malt extract comes into contact with the starch solution.

Ten minutes after the malt extract is added to the starch 1 cc. of the mixture is added to the first iodine tube.   This procedure is repeated at appropriate intervals until the color of the dextrin tube has been passed.   The color of the tubes is compared with the color of the dextrin tube and that tube which exactly matches the standard is taken as the end-point.   The result is reported to the nearest one-half minute.

Calculation of Alpha–Amylase Activity

In the method outlined above 1 cc. of 2% starch solution is acted on by 0.5 cc. of diluted (1 : 10) malt extract, or by 0.05 cc. of original malt extract.   Then, $1/0.05 = 20$ cc. of 2% starch solution is acted on by 1 cc. of original malt extract.   If the conversion of the starch to dextrin takes place in c minutes, in 1 hour 1 cc. of original malt extract

will convert $\left(\dfrac{60}{c} \times \dfrac{1}{0.05}\right)$ cc. of 2% starch solution. Formula:

$$\frac{60}{c} \times \frac{1}{0.05} = \text{alpha-amylase value.}$$

The method as outlined above is well suited to rapid control work without departing from the principle of the Wohlgemuth method (1908). It is accurate, since it is possible to obtain checks with it to within one-half minute in conversion time. It is rapid since it utilizes the same solutions and the same malt extract as used in the determination of diastatic power according to the official method of the A.S.B.C., thus eliminating the necessity of preparing special solutions and a special malt extract.

Experimental

In order to determine the effect of beta-amylase on the alpha-amylase test, the alpha-amylase test was performed with a papain-digested extract of barley as the source of the beta-amylase. Five grams of finely ground barley were extracted for 21.5 hours at 20° C. with 50 cc. of water containing 0.5 g. of papain (Sallans and Anderson, 1938). The diastatic-power values of two different barley samples were, respectively, 323° and 350° Lintner. The two barley extracts, although very high in diastatic power, had no perceptible color effect on the iodine test tube, even after 2½ hours of action, when tested for alpha-amylase activity according to the authors' method.

Table I shows definite correlation between the two methods when the alpha-amylase value is compared with milligrams starch liquefied by the viscosity method. One-half of the true value of the malt is obtained with both methods when the malt extract is diluted to one-half its original concentration. A proportional correlation of this nature is evidence of the reliability of the two methods. However, when the alpha-amylase value and milligrams of starch liquefied are compared with "liquefons per 10 cc.," which is a measure of the actual enzyme content of the malt extract (Józsa and Johnston, 1935), the proportionality no longer holds true. No attempt is made in this paper to explain this inconsistency.

Table I also shows the difference in results with the modified Wohlgemuth method when Merck's and Baker's dextrins are used in the preparation of the standard dextrin tube. Baker's dextrin gives results consistently lower than does Merck's dextrin. To avoid confusion, results are reported only in terms of Merck's dextrin in the following tables.

Table II and Figure 1 do not show a very high degree of correlation between alpha-amylase activity and diastatic power, but they do show a general tendency toward correlation between the two values.

TABLE II

COMPARISON OF ALPHA-AMYLASE VALUES, DETERMINED WITH THE MODIFIED WOHLGEMUTH METHOD, AND DIASTATIC-POWER VALUES, EXPRESSED IN DEGREES LINTNER

(Diastatic power values arranged in ascending order.)

Malt number	Alpha-amylase value	Diastatic power
1	41.4	112.0
2	38.7	114.0
3	41.4	158.0
4	53.3	159.0
5	57.1	162.0
6a	58.5	170.0
6b ($\frac{1}{2}$ conc.)	29.6	—
7a	61.5	174.0
7b (check)	61.5	—
8a	52.2	177.0
8b (check)	52.2	—
8c (check)	53.3	—
9a	64.9	181.0
9b (check)	64.9	—
10	58.5	183.0
11	60.0	190.0
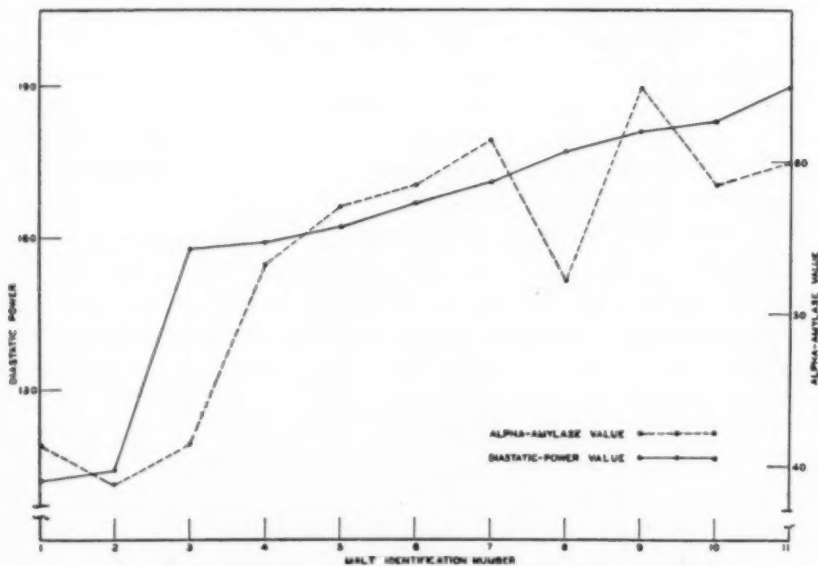
Fig. 1.   Comparison of alpha-amylase and Lintner values.

According to the data in Table III the greatest activity of alpha-amylase appears to lie between 50° and 60° C.   Because of lack of time only one experiment was conducted at these different temperatures.   The data are included in this paper with the suggestion that further work can be done along this line with the thought in mind that perhaps better differentiation between malts will be effected at a higher temperature than at the temperature of 30° C.

TABLE III

THE EFFECT OF TEMPERATURE ON THE ALPHA-AMYLASE ACTIVITY OF MALT

Temperature	Alpha-amylase value
30°C.	55.2
40°C.	94.1
50°C.	137.1
60°C.	102.1
70°C.	Less than 30

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THE PERMEABILITY OF BREAD BY AIR

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During a study of the effect of temperature on dough properties by Baker and Mize [1] it was noted, as shown in Charts 9 and 10 of that paper, that there was a difference during baking in the pressure of two doughs which were identical in all respects except state of oxidation. The pressure in the oxidized dough became very much higher during baking than in the unoxidized dough and remained high to the end of the baking period. This difference in the ability of these doughs to hold gas pressure suggested that the final baked breads under these two conditions must have been different in their porosity. In other words, the one that withstood the greater pressure must have produced a bread which did not permit gas to pass through it readily, whereas the other with less resistance to pressure must have produced a bread which permitted gas to pass through it more freely.

After numerous devices had been tried to test that hypothesis, the machine shown in Figure 1 was developed. This is a device for drawing air through bread and metering the amount of air so obtained. In operation, a special blower of constant speed draws air through the sample of bread across a fixed area and passes it into an air meter of a wide range. This meter is calibrated to an arbitrary scale which can be converted into liters of air per minute if desired. The bread is subjected to increased negative pressure when a low rate of air flow takes place. This pressure is sufficient to distort slightly a thin slice of bread. The circle which determines the area of the bread through which air is drawn is bounded by a slightly elevated flat ring. The bread lying upon this ring is drawn tight by the negative pressure of the machine. If a freshly cut slice is used which has had no drying, a satisfactorily tight seal is accomplished. Also, a ring is provided which can be pressed above the seal to assure no leakage. It is necessary to make certain, in case sliced bread is used, that the particular slice being tested has no noticeable holes such as are apparent if the slice is held up to a fairly strong light. These open-textured slices should be discarded unless the device is being used to indicate the presence of holes in bread. The crust has little effect. Tests on a half loaf are more reproducible and are usually slightly higher than on slices.

[1] J. C. Baker and M. D. Miz Effect of temperature on dough properties, I, Cereal Chem. 16: 517–533, 1939.

For permeability readings one should select the most uniform area obtainable in a slice, preferably located in the same zone in all slices —that is, either in the top or the bottom.   In our work we prefer to record the values read from the bottom half.   That test which gives the least passage of air is taken as the reading and is the one most nearly duplicated on successive tests with other slices of a loaf.   In
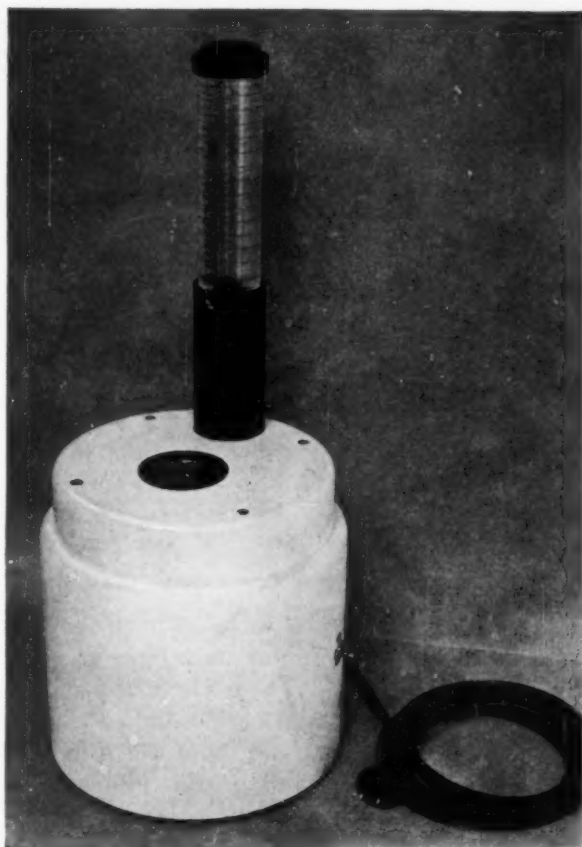
Fig. 1.   Device for drawing air through bread.

other words, when testing the permeability one attempts to find how much air can be drawn through that portion of the texture which represents the normal character of the bread.   In testing sliced bread not less than five pieces should be averaged.

A wide range of commercial breads, as well as laboratory breads of various composition which have been baked under a variety of conditions, have been tested in this machine.

Figure 2 gives the correlation between cell size and permeability and is determined on a large series of commercial breads by skilled observers. We are indebted to S. J. Lawellin and M. D. Mize for making the determinations on which this chart is based. It is to be noted that the permeability increase is approximately proportional to the increase in cell size. The larger the cells become the more permeable is the bread. It is also to be noted that breads which have been twisted are generally much less permeable than the untwisted bread. These results are in agreement with our previous observation that the finest-textured breads were obtained from doughs which had a high pressure during baking, whereas doughs which gave a low pressure were generally of coarse texture.
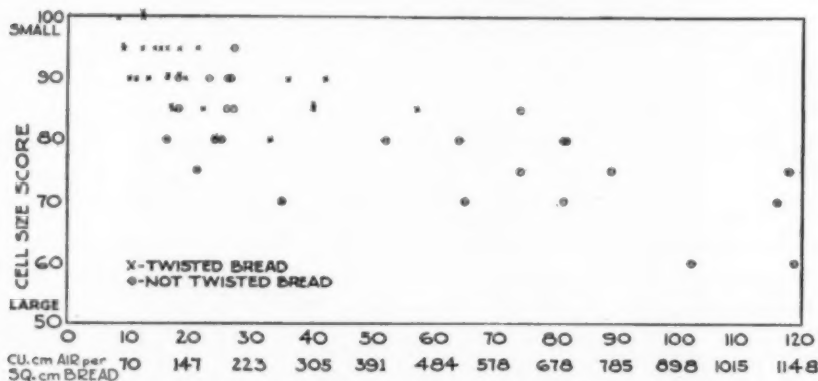
Fig. 2. Relation of permeability to cell size—commercial pan bread slices.

A study has been made of several variables in their relation to permeability. The list is not complete and much more information needs to be obtained by further work. Those factors which decrease the permeability are oxidation, fermentation, protein content, twisting of dough, and baking in a closed pan, and those which increase the permeability are semi-solid shortening and yeast and water content. It is to be noted that in general those dough conditions which improve bread quality, such as oxidation, protein content, twisted loaf, fermentation, etc., decrease the permeability of the bread, whereas factors which have a tendency to produce bread of coarser texture have also a tendency to increase the permeability.

The more permeable bread cools at a more rapid rate. A permeable slice dries rapidly; the flavor seems to disappear sooner in such bread and the crumb stales more rapidly. In the last instance it is possible that the increased staling observed is somewhat associated with the more rapid rate at which water dries out from the crumb. Fresh bread decreases in permeability, at first rapidly, then very slowly.

A study of commercial bread shows that the bread of some bakeries keeps within a fairly narrow range of permeability, whereas other commercial breads vary over a wide range of permeability.   In general, those bakers who keep within a narrow range bake the less permeable bread and those whose breads vary widely bake the more permeable kind.   Breads from some small bakeries are usually highly permeable, excepting those made without the use of shortening, in which case they are generally fairly impermeable even when of very coarse texture. Apparently shortening has an effect which prevents the cellular structure from finally closing or sealing the pores.   This is directly opposite to the action of shortening during the earlier stages of baking, as shown in a previous paper.[2]

QUALITY TESTS ON HARD RED WINTER WHEATS [1]

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(Read at the Annual Meeting, May 1939)

The question of the relation of protein content of wheat to baking strength and baking quality has received so much attention that it might seem superfluous to add another paper to the great number already published on this subject.   However, certain modifications of methods recently used in this laboratory have led to conclusions somewhat different from those previously reported for winter wheats, and more in agreement with the commercial practice of buying on protein content.

As it is proposed to discuss estimates of both baking strength and baking quality, it is necessary at the outset to differentiate these terms clearly.   The classical definition of a strong flour given by Humphries is "one capable of producing bold, well-piled loaves."   This definition clearly refers to what we shall term *strength*.   It involves no consideration of the differences in handling properties nor of baking procedure necessary to produce the large well-piled loaf.   It should be recognized that it is possible to have flours of equal strength but of very different qualities, and *vice versa*.   There has been a tendency to confuse these two baking factors, although a number of cereal chemists have stated the differences clearly.   Thomas (1917) referred to strength as "that quality which enables the baker to produce a loaf of bread of large volume and of good texture by use of the proper ingredients together with the proper mixing, fermentation and baking."   He recognized

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[2] Baker and Mize, Effect of temperature on dough properties, II, Cereal Chem. 16: 682–695, 1939.
[1] Contribution No. 62 from the Department of Milling Industry.

that there are rather wide variations in the physical properties of doughs made from different flours.   More recently Blish and Sandstedt (1935) again emphasized this point, and proposed the theory that the protein content of wheat may be regarded as the ultimate criterion of strength.   They stated that owing to various characteristics of wheats it might be necessary to employ different methods for obtaining the expression of this strength.   The concept of baking strength seems to be relatively simple and might be stated concisely as the capacity of flour to produce large loaves of good texture and the ability to confer this property to blends with softer wheats.

The term *quality* has so many applications and has been used so indiscriminately that it is very difficult and perhaps even unwise to attempt to define it.   If the discussion of baking quality is confined to bread flours, there are clearly two legitimate applications of the term. Its most general use is in reference to the suitability of a flour for a specific bread-making process.   Used in this way, there can scarcely be more than two sorts of quality, namely satisfactory and unsatis-factory.   Occasionally, price consideration may induce bakers to tolerate and use flours which ordinarily would be considered unsatis-factory.   For example, a typical strong hard winter baker's patent might be regarded by one baking company as of satisfactory quality, whereas another company using a procedure designed for a different type of strong flour, say a hard spring, might regard it as of poor quality, even while recognizing the existence of its high strength. Again, there is the case of high-protein flours, high in baking strength but of doubtful quality for the commercial baker's use.   What baker would judge a 17%-protein Turkey flour to be superior in quality for bread making to a normal 12% patent?   Thus high strength may be associated with poor quality from the standpoint of suitability for a given purpose.   On the other hand, low-strength flours may be deemed eminently satisfactory and hence of good quality for certain purposes such as for cakes or for pastry.

The other general application of the term *quality* is in reference to differences expressed as divergences from expectation based on protein content.   The value of loaf volume to be anticipated from a considera-tion of the protein content is expressible as the regression coefficient or the line of regression of loaf volume on protein content, and is deter-mined from a large number of observations.   If, then, the sample hav-ing been tested by the most favorable formula available produces a volume much less than that estimated from the regression line, one must conclude either that its gluten protein is of lower bread-making potentialities than normal, or that the formulas applied were inade-quate properly to express the volume of the protein.   Blish and Sand-

stedt (1935) expressed this idea as follows: "When the test loaf fails to fulfill the expectations that its protein content would justify, it is likely to be suspected that the gluten was 'weak' or of inferior quality. Experience has shown however that there is every justification for challenging the baking method rather than the flour itself."

Unquestionably the possibility that the baking method is inadequate must be carefully considered.   There is however little doubt that classes or varieties of wheat may differ materially in respect to the optimum baking results obtainable.   This means that quality differences of the gluten proteins may exist.   The question to be considered is: Shall we refer to such flours as "weak," which means the same as "low strength," or merely as of poor quality?   It is perfectly obvious that *weak* and *low quality* should not be regarded as synonymous because one may have two high-protein flours both "strong" in the sense defined by Blish and Sandstedt, but one poorer in quality than the other, as shown by its failure to produce as great loaf volume as its protein content would lead one to expect.   The same sort of differentiation can be observed with low-strength flours.   Without laboring this point further, it might be well to consider some of the ideas that have been held concerning the relation of protein content to baking performance.

For many years it was thought that the extent to which protein could be expressed in loaf volume varied with the amount of protein present.   Thomas (1917), Stockham (1920), Shollenberger (1923), and others published results of extensive baking tests which led to the conclusion that the relative effect of protein content on loaf volume is greater in the lower-protein range than in the higher.   The data of Thomas (1917) and Shollenberger (1923) have been reproduced graphically in Figure 1.   Such data clearly justified the conclusion stated above.   Bailey and Sherwood (1926), using data obtained from the crops of 1921 to 1925 inclusive, calculated the formula of the curve which would best represent the relation between loaf volume and protein, and found it to be hyperbolic, indicating that "each increment of increase in protein content results in a diminished increment of increase in loaf volume."

Larmour (1931) reported the study of 665 samples of Canadian hard red spring wheat grown in one season.   He concluded that the curvilinearity of the relation between protein and loaf volume was limited to the extreme ranges of protein, and that when these were eliminated from the series, the regression of loaf volume on protein was linear between the limits of 7.0% and 15.9% when the loaf volume obtained with the bromate baking formula was used.   This conclusion seems to receive confirmation from the work of Aitken and Geddes

(1934), which showed that composites representing the range from 12.1% to 16.5% gave essentially a linear relationship between protein content of wheat and loaf volume as obtained by means of the malt-phosphate-bromate baking formula. These data are reproduced graphically in Figure 2. A high degree of correspondence exists between the two sets of data, which were obtained on crops three years apart. Larmour's data were obtained by examination of individual samples, while those of Aitken and Geddes were procured on composites made up from 7500 samples.

There seems little reason to doubt that as far as the hard spring wheats are concerned, loaf volume can be regarded as a linear function
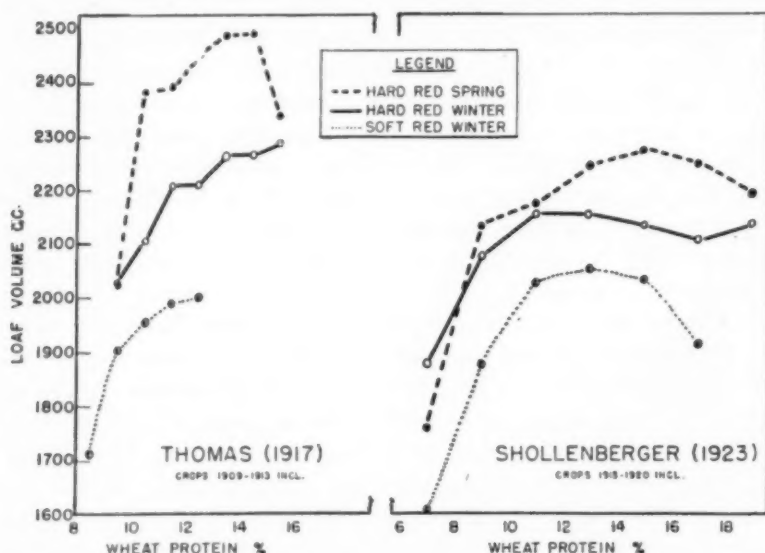
Fig. 1. The relation between loaf volume and protein content of wheat as shown by the data of Thomas (1917) and Shollenberger (1923).

of the protein content of the wheat, or flour, provided the baking is done by a suitable method.

With the hard red winter wheats, there never has been much evidence of a high degree of correlation between the loaf volume and protein content. Referring to Figure 1 again, it can be seen that although Thomas's data indicated a continuous increase in loaf volume with increasing protein content, Shollenberger's showed that beyond about 12% there was no further increase and even some indication of a decrease. Inspection of the curves for Shollenberger's data would lead to the general conclusion that the correlation between loaf volume and protein ought to be higher in the case of the hard red spring than in the case of the hard red winter wheats, because the former continued to

show progressive increases in loaf volume up to about 15%.   The data of both Thomas and Shollenberger would lead to the further conclusion that beyond 12% in protein content the hard red spring wheats are indubitably higher in strength than the hard winter wheats of corresponding protein content.   It is curious that Zinn's (1923) correlations showed the highest values for Kansas winter wheats, + .75.   This appears to contradict the conclusion to be drawn from Shollenberger's
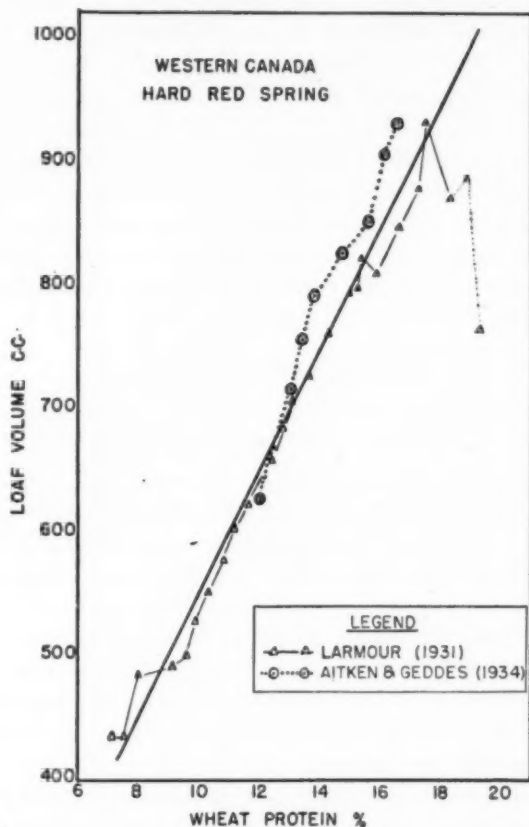
Fig. 2.   The relation between loaf volume and protein content of Canadian hard red spring wheat as shown by the data of Larmour (1931) and Aitken and Geddes (1934).

data, which were based on a very large number of samples grown during the years 1915–1920 inclusive. Our recalculation of Zinn's correlation for Kansas wheats shows that it was in error; it should have been + .42 instead of + .75.   Blish and Sandstedt (1925) reported a correlation between loaf volume and protein content of + .30, which is quite out of line with Zinn's originally reported correlation for Kansas wheats, but corresponding in magnitude to the corrected value.

It has seemed to the authors that it is practically impossible to accept as fact that there could be such a high relationship between protein and strength in hard red spring wheats and such an exceedingly low degree of correlation between these factors in hard red winter wheats.   Probably failure to show a greater degree of correlation in winter wheats ought to be attributed to inadequacy of baking methods used in testing them.   This view is strengthened by the observations of many investigators whose data indicate that the winter wheats of ordinary commercial protein range are fully equal in baking strength to spring-wheat flours of the same range.   It would seem strange furthermore that commercial millers have continued paying premiums for high-protein wheat.   Without accepting these reasons as more than indications of a probable relationship between strength and protein content, it was decided to assemble a series of samples suitable for the purpose of studying with some degree of exactitude this relationship in general, and also in its particular application to a number of the principal varieties at present being grown or in the process of being introduced in the American southwest.

Experimental Discussion

Through the cooperation of A. L. Clapp of the Kansas Agricultural Experiment Station, it was possible to obtain pure samples of the principal varieties of wheat grown in Kansas.   These samples were produced from seed supplied by the College, and were grown in 55 counties of the state.   The varieties represented were Turkey, Black-hull, Kanred, Tenmarq, Cheyenne, Chiefkan, Early Blackhull, Kawvale, Clarkan, Harvest Queen, and Michigan Wonder.   The first seven are classed as hard red winter wheats and the last three as soft red winter wheats; Kawvale is classed as semi-hard.   In this paper only the first six varieties will be discussed.   They are those of principal interest, and of greatest distribution, and the numbers in the series as finally made up were the largest.

All the individual samples were harvested under supervision, shipped to the College, and there threshed.   They were then analyzed for protein and grouped on this basis.   Each sample included in a composite was carefully scrutinized for damage, and a number were discarded on that account.   No composite contained less than three samples, each from a different county, and many in the middle protein range contained ten or more.   The well-mixed samples were milled on the Buhler mill, the flours were analyzed, aged for three weeks at room temperature, and then placed in the cold storage room at 3° C.

Material of this sort has the advantage that the varieties are known to be pure and that the whole range of protein occurring in a given

season is reasonably well represented. This is the most desirable method for comparing varieties, and is the one to be recommended whenever it is possible to obtain a sufficient number of samples. The method of comparing samples grown in one place under the same environmental conditions is commonly used, and undoubtedly possesses certain advantages, but it must be recognized that the data so obtained are not so comprehensive as when the whole protein range of the variety is studied. This seems particularly true in a consideration of qualitative differences that may be brought out by physical methods.

The flour samples were baked by two different formulas. Formula I, which was deemed the best available at the time, involved the use of the following ingredients: Flour 100%, water as required, yeast 2%, sugar 6%, shortening 3%, salt 1.5%, dry milk solids 4%, potassium bromate 0.001%, $NH_4H_2PO_4$ 0.05%, malt extract (120° L.) 0.35%. The doughs were mixed to optimum consistency, fermented, proofed, and baked according to the time schedule of the American Association of Cereal Chemists standard method using the tall, narrow pan. Punching was done by means of the National Pup Sheeting Rolls, and molding by the Thompson Laboratory Molder. Doughs were mixed with 200 g. of flour and divided immediately after mixing. Mixing was done by means of the Swanson-Working dough mixer.

This formula was decided upon in consultation with Karl F. Finney, who had been carrying on an extended investigation of various formulas suited to the requirements of hard winter wheats. While recognizing that it is difficult to obtain the information desired concerning baking strength of different varieties at different protein levels by application of a single formula, it was at the time thought that this would most probably give more information than any other single baking test. This test is comparable in many respects to the malt-phosphate-bromate test used in the Canadian laboratories. The work of Aitken and Geddes (1934) showed that with hard spring wheats this gave the greatest range and was adequate to measure the strength over a wide range of protein contents. The formula as modified for use with the winter wheats contains less yeast and more sugar, with shortening and dry milk solids additional. Finney and Barmore (1939) have advanced excellent reasons for the use of such combination of ingredients in experimental baking of hard winter wheats.

After the first baking was completed the remaining flours were stored in the cold room at 3° C. Sometime later a second baking was made using a formula which was devised as the result of observations made by Finney and Barmore (1939) and by Ofelt (1939). Finney and Barmore observed that with 4% dry milk solids in the formula and increasing increments of potassium bromate, the majority of

hard winter wheats appear to show optimum loaf volume, together with excellent crumb characteristics, with 0.004% to 0.006% potassium bromate.

Ofelt (1939) made an extensive study of the effect of increasing amounts of potassium bromate with 6% dry milk solids, using as a check a comparable series without milk. He found that while without milk the optimum bromate requirement varied considerably, with 6% dry milk solids there appeared to be a general optimum at about 0.004% potassium bromate with unbleached, experimentally milled flour. This means that a flour which ordinarily requires 0.001% or less bromate and decreases in volume with higher dosages with a formula having no milk, may in the presence of 6% milk attain its maximum volume at say 2 mg. dosage, and maintain it through 3, 4, and even 5 mg. dosages. In short, the milk in this concentration appears to create a condition in which an excess of bromate above that required for maximum development does not create the condition characteristic of overdosage. At the same time a flour requiring a high dosage can apparently make use of the bromate. The presence of 6% dry milk solids seems to establish a peculiar sort of tolerance toward bromate, so that it is possible to use sufficient for those flours requiring high dosages, without running the risk of overdosing those flours in the series that require less bromate. Some typical results from Ofelt's (1939) data are shown in Figure 3. The effect discussed above is quite evident and needs no further elaboration.

As a result of these experiments it was considered advisable to re-bake the protein series, and this was done, using formula I modified as follows: 6% dry milk solids was used in place of 4%; both malt and ammonium phosphate were omitted; and 0.004% potassium bromate was used in place of 0.001%; otherwise the ingredients and conditions were the same.

One exception was made in the case of the Tenmarq variety. This is known to require considerably less bromate than the other winter-wheat varieties, and since there was material sufficient for only one baking it was deemed inadvisable to take the risk of overdosing. Consequently 0.003% was used with this variety.

The baking data by both formulas are given in Table I, and are shown graphically in Figure 4.

It can be seen from the graphs that in most instances formula I gave loaf volumes which show a relationship to protein content comparable to that shown by Thomas (1917) and Shollenberger (1923). They increased with increasing protein content to about 12% or 13% and thereafter either decreased or exhibited a very slight upward trend. Exceptions to this were observed in Tenmarq and Cheyenne, the

former showing virtually a linear relationship throughout the protein range, and the latter a maximum at 14.7%.

With formula II there was a notable change in the relationship of loaf volume to protein content. Turkey, Blackhull, Kanred, and Chiefkan gave loaf volumes which continued to increase with increasing protein content throughout the range of the latter. In the case of Kanred the highest protein sample, containing 17.7%, was 10 cc.
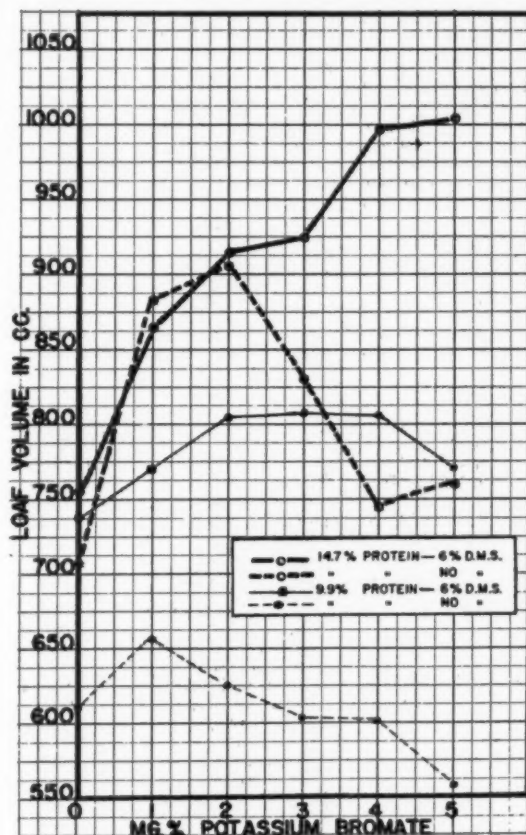
Fig. 3.   The effect of dry milk solids in relation to various increments of KBrO₃ in the baking formula.

lower than the one next below. This was probably due to insufficient bromate. This particular sample was rebaked with 0.006% bromate and gave a volume of 1,073 cc., which is more nearly in line with the other volumes for this variety. Attention should be directed particularly to the fact that in the lower protein ranges of these varieties the loaf volumes obtained by formula II agree well with those by formula I, which would indicate that the 4-mg. dosage had not penalized those

TABLE I

BAKING DATA AND DESCRIPTION OF SAMPLES

Variety	Flour protein	Formula I		Formula II	
		Loaf vol.	Texture	Loaf vol.	Texture
		cc.		*cc.*	
Turkey	8.2	708	8.3	658	8.0
	9.5	708	8.3	733	8.0
	10.1	752	9.0	743	8.5
	11.0	785	9.4	798	9.5
	11.7	822	9.1	843	9.5
	13.2	812	9.4	898	9.0
	14.7	835	8.5	1003	9.0
	16.5	858	7.8	1020	7.0 open
	17.9	830	7.2	1078	7.0
Kanred	9.4	725	9.0	655	7.5
	11.0	727	9.4	770	8.5
	12.3	787	9.1	850	9.0
	13.9	822	8.8	930	8.5 open
	14.9	790	8.5	958	8.0 open
	16.2	778	8.1	1038	7.0 open
	17.7	748	7.1	1028	7.0 open
Blackhull	10.0	752	8.8	750	8.5
	11.2	775	8.5	783	10.0
	12.2	792	8.5	840	9.5
	13.8	810	7.9	863	9.0
	15.2	820	7.6	945	8.0 open
	16.3	830	7.2	1010	8.0 open
	17.6	840	6.6	1088	7.0 open
Tenmarq	8.6	730	8.6	653	8.0
	9.2	750	8.6	668	8.5
	10.1	808	9.3	750	9.5
	10.7	822	9.4	773	9.5
	12.7	908	9.4	860	9.0
	13.4	925	9.4	933	8.5
	14.9	962	9.7	975	7.5 open
	17.0	1038	8.8	1075	7.5 open
Cheyenne	8.2	702	7.9	678	8.0
	9.1	742	7.9	705	8.5
	10.1	752	7.9	725	8.5
	11.0	832	9.4	753	8.5
	12.4	840	8.7	820	9.0
	13.7	842	8.1	845	9.0
	14.7	892	8.1	920	8.5
	16.3	872	7.4	865	8.0
Chiefkan	10.4	688	8.3	690	8.0
	11.0	696	7.7	679	8.0
	12.1	710	7.4	717	9.0
	13.3	700	7.4	755	9.5
	14.6	750	7.5	800	7.5
	16.9	768	6.9	898	7.0 open
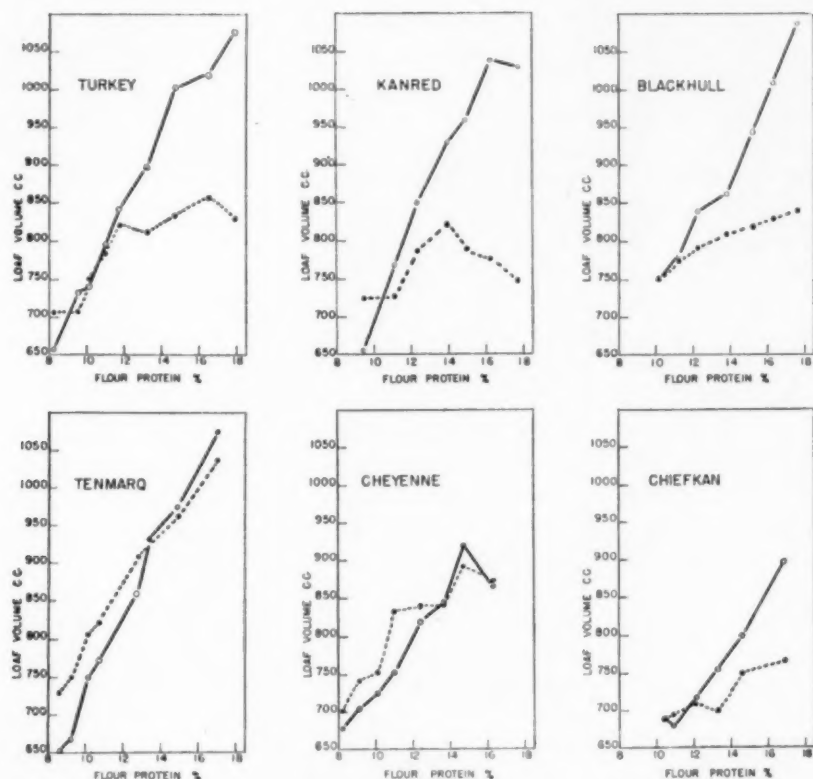
Fig. 4.   The relation between loaf volume and protein content of flour as shown by two different baking formulas for six varieties of hard red winter wheat.
The broken graph line represents formula I; the unbroken line represents formula II.

samples any more than the 1-mg. dosage.   It appears that the curves obtained by formula II are merely the projection of the initial portion of those obtained by formula I, which of course is in line with what one might be led to expect from theoretical considerations.

The case of Tenmarq is somewhat different from the others, inasmuch as the loaf volumes by both formulas show a linear relationship with protein content throughout the range of the latter.   The difference is in the slope.   It looks as though the line had been pivoted at a protein content of about 13%.   This would indicate that the 3-mg. dosage depressed the lower-protein samples of the series and increased the volume of the higher ones, a result that was anticipated from Ofelt's (1939) earlier observations.   Cheyenne shows evidence of similar characteristics.   It has been generally thought that Cheyenne requires rather heavy dosages of bromate, but the results obtained in this study tend to cast some doubt on that conclusion.   One curious result of the second baking is that the graphs for the different varieties

are so nearly the same that it is almost impossible to show them on the same figure. That is the reason for presenting them as six separate units in Figure 4.

Attention should be directed particularly to the two graphs of Chiefkan, and especially to the lower-protein samples. The three lowest samples gave essentially the same loaf volume by both formulas I and II, indicating that the additional 3 mg. of bromate used in formula II had no harmful effect. This means further that the volumes represented may be considered the greatest obtainable with any dosage of bromate. As the curve by formula II is virtually linear, it seems reasonably safe to assume that it represents the maximum loaf volume to be expected from samples of this variety at the various protein levels studied. Even if one were not prepared to accept this conclusion for the whole series of Chiefkan flours, it ought to be acceptable for the three lower-protein samples. Assuming the validity of this conclusion, it is interesting to note that the loaf-volume values for this variety are materially displaced toward the right as compared with the other five varieties shown in Figure 4.

After studying these data more carefully the authors decided to determine what might be considered the theoretical relationship between loaf volume and protein content for hard winter wheats in general. According to Quisenberry and Clark (1938) 91% of the total hard red winter wheat acreage in 1934 was represented by Turkey, Blackhull, and Kanred. It seemed reasonable therefore to use these varieties as a criterion. Loaf volume by formula II and protein content of flour give a correlation coefficient of + .980 and a regression coefficient of 43.8. The regression of loaf volume on protein content of flour, based on the data of these three varieties, is given in Figure 5. The various points lying about the line represent the individual values from which the regression was computed. There is little doubt that all these values may be considered samples of one population. In other words, it is improbable that Turkey, Blackhull, and Kanred are differentiated in respect to loaf volume at any point in their protein ranges.

The values for Tenmarq and Chiefkan are also shown in Figure 5 and are indicated by means of the connected points. It can be seen that the data for Tenmarq fit the regression practically as well as any of the standard varieties.

Chiefkan is undoubtedly an example of wheat possessing distinctly inferior quality within a class. The baking strength over its whole range of protein is markedly different from that of the typical varieties. It is not only displaced to the right but shows evidence of a lower regression coefficient, indicating that loaf-volume response to increas-

ing protein content is less than in the standard varieties. At comparable protein levels its volume is approximately 100 cc. lower than the standard. Another way of comparing them is to note that a volume of 800 cc. requires 11.2% protein for standard varieties and 14.6% for Chiefkan. There can be little doubt that this variety is sharply differentiated from the others and is distinctly inferior to them.
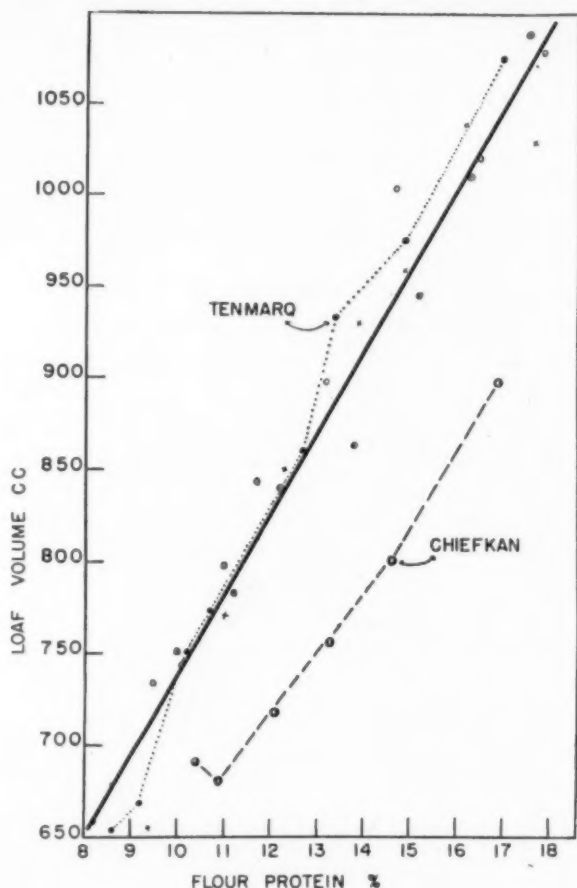
Fig. 5.   The regression of loaf volume on protein content of flour.

It might be argued that the baking formula used in this instance is not adequate for the purpose of indicating the inherent strength of this variety. However reference to the data in Table I or to Figure 4 will show at once that this assumption is not tenable, at least in connection with any of the baking ingredients that are commonly used at the present time. Both formulas gave practically the same results in the lower protein range. Obviously if more bromate were required,

the graph obtained with the data from formula II ought to have been distinctly displaced upward in the low-protein range.   As this does not occur it would indicate that there is sufficient bromate and that failure for the lower-range samples must be attributed to qualitative differences comparable to the sort of differences that are thought to exist between classes of wheat.

From a consideration of the results obtained with formula II, it is evident that the relationship between protein content and loaf volume is definitely linear throughout the range from 8.2% to 17.7% flour protein.   This is excellent support of the contention that protein content is a measure of baking strength within the same varieties, but not always between varieties, as shown by Chiefkan.   The astonishing thing is that it could be demonstrated by the application of one single formula to different varieties over a wide range of protein.

Physical Characteristics of Doughs

For a number of years much interest has been shown in various physical methods for estimating baking strength and baking quality. Unfortunately it was not possible to make comparative tests with this series of samples because the different types of machines were not available, and the amount of flour was quite limited.   The flours were examined by means of a new modification of the Swanson-Working recording dough-mixer designed by Working for use with small samples of flour.   A photograph of this instrument is shown in Figure 6.   The mixing principle is essentially the same as that used in the older machine described by Swanson and Working (1933) but the bowl and mixing head have been reduced in size so that 35 g. of flour is required instead of 400 g.   A number of other modifications dealing with transmission of torque have been introduced.   The instrument will doubtlessly undergo further refinement by the present manufacturers.

Mixing curves on all samples of the six hard red winter wheat varieties heretofore discussed are shown in Figure 7.   It should be pointed out first that the curves obtained with this micro-mixer are sharper than those customarily produced on the larger machine.   This is due partly to higher speed and partly to the somewhat different relationship of area of the pins in both the bowl and the mixing head. In general the small mixer produces a somewhat more pronounced differentiation between various types of flours.

It is not the purpose of this paper to attempt to interpret all the characteristics of these mixing curves in terms of baking performance of the flours, but rather to call attention to the extent to which flours may be distinguished by this means.   Looking over the whole series of curves, one can see that they vary over a wide range.   The highest-

protein Cheyenne sample may be taken as one extreme, and almost any of the Chiefkan samples as representing the other.   The Cheyenne curve referred to has a long mixing time, $7\frac{1}{2}$ minutes, indicating rather slow dough development; the band is broad, and continues so over a
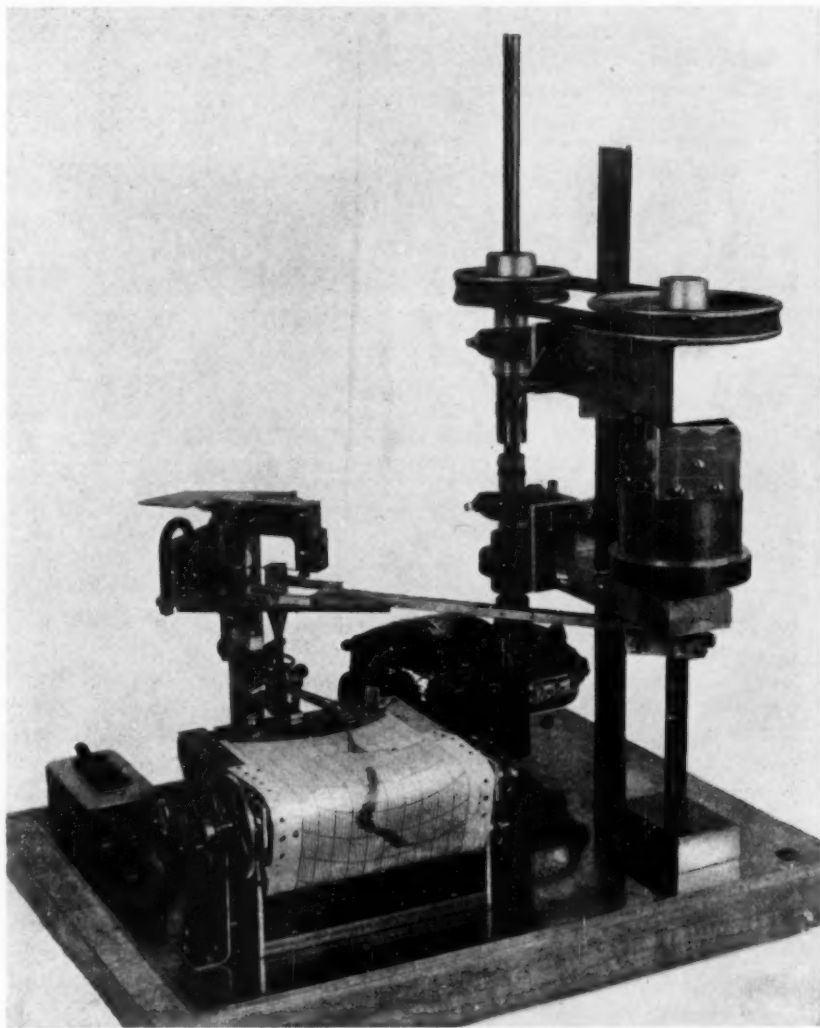
Fig. 6.   The original recording micro-mixer constructed by Working.

long period of time; the rate of decline from the maximum is slow. This curve is typical of high-protein Turkey, Tenmarq, Cheyenne, and many spring wheats.   The Chiefkan curves show very rapid rise to a maximum, $1\frac{1}{2}$ minutes; the band is narrow except at the peak; the rate
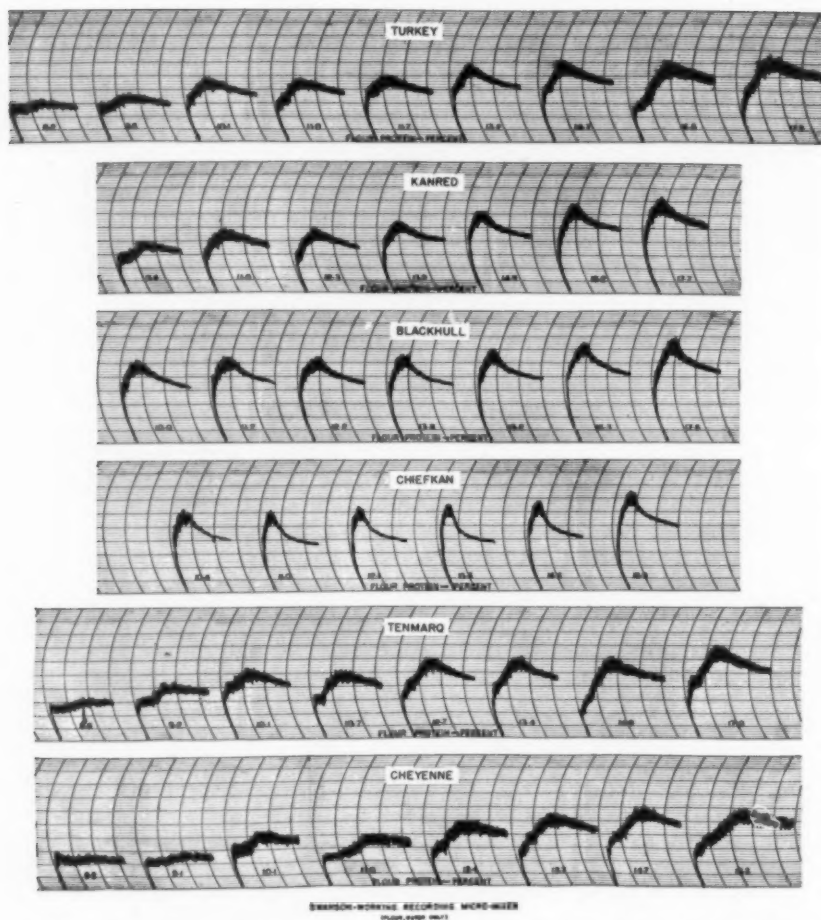
Fig. 7.   Recording-micro-mixer curves for six varieties of hard red winter wheat at various protein levels.

of decline from the maximum is very rapid and the curve tapers off to an exceedingly thin line, indicating great decrease in resiliency of the dough. There is also another type of curve shown by the lowest Turkey sample. This is very flat, has considerable width, and is low. This seems to be typical of the low-protein Turkey, Tenmarq, and Cheyenne.

Perhaps the most striking thing in the series of curves is the similarity of the Blackhull and Chiefkan. These seem to be modifications of one type. The question arises, how can the differences in curve type of Turkey and Blackhull be reconciled with the fact that they appear to be of equal baking strength, and how can the similarities of Blackhull and Chiefkan be reconciled with the fact that they are

distinctly of different baking strength?   The obvious answer is that the curve characteristics must be attributable to *qualitative* differences between flours.   It becomes clearly evident from examination of the curves that not only do varieties differ in respect to the rate at which their doughs can be mixed to the maximum resistance consistency, but they also differ markedly in the manner in which they behave after this maximum has been passed.   The curves thus give information not only concerning the mixing requirement but also concerning their behavior during prolonged mixing.   Although they are similar in type it is possible to distinguish between Chiefkan and Blackhull because the former requires consistently shorter mixing time and breaks down more rapidly and more completely than the latter.

Regarding the difference between Turkey and Blackhull, the curves show a marked *qualitative* distinction among varieties in respect to behavior.   This has been recognized for a long time by the commercial bakers.   The baking tests heretofore described have shown these varieties to be equal in strength; the curves show them to be different *qualitatively*.

Tenmarq and Cheyenne appear to be similar to Turkey in dough characteristics and equal to it in baking strength with the exception of the highest-protein Cheyenne sample.   Unfortunately there is not sufficient information available to decide whether or not Tenmarq is qualitatively different from Turkey.   It was baked with 0.003% bromate in place of 0.004% and thus it is impossible to say that the two varieties are the same from the standpoint of the treatment required to bring out the maximum baking strength.   It is currently believed, however, that Tenmarq requires less bromate than Turkey.   From that standpoint it may be said to be qualitatively differentiated from Turkey, but there is no definite evidence in the data herein presented to support this condition.

While certain differences between some varieties are very obvious, it can be seen that within some of the varieties rather marked differences in shape of the curves exist.   This applies particularly to Tenmarq, Kanred, Turkey, and Cheyenne.   The curves in the low-protein samples tend to be low and flat; as the protein increases, they become sharper and higher.   In these varieties the height of the curve appears to be fairly closely related to the protein content, and thus may be taken as an indication of strength.   In contrast to these four varieties, Blackhull and Chiefkan exhibit a remarkable uniformity of curve type throughout the protein range.   The range is less than in the case of the other varieties and one cannot state definitely that they would flatten out in the case of low-protein samples, but there is little evidence of any such tendency.   Until further data are available it

seems justifiable to conclude that the curve type of these varieties is fairly uniform and persists through any range of protein content that might be encountered. Some evidence in support of this belief is to be found in the curves made with Clarkan, a soft red winter wheat selection from Blackhull. Clarkan at 9% protein gives curves somewhat similar to the Chiefkan curves. It seems safe to state that this particular curve type is a persistent and uniform characteristic of the Blackhull group of wheats, and it may be used with confidence to distinguish them from the Turkey types, with the possible exception of the higher-protein Kanred samples.

It may well be asked what use can be made of curves of this sort when so much variation exists, and particularly when such varieties as Blackhull and Turkey, both of equal strength, show such different curve characteristics, and furthermore how could one distinguish Chiefkan? In the first place, from the commercial point of view, it is highly desirable that millers should know the kind of wheat they are using. When Blackhull was introduced, it caused a great deal of trouble, mainly because bakers did not know how to use it. At present it is widely recognized as a useful wheat and complaints about flour produced from it have practically disappeared. Millers and bakers, if convinced of the strength of a wheat, can undoubtedly discover how to use it to advantage. But in order to do so they must gain some knowledge concerning its characteristics, and that involves being able to distinguish it. There is no doubt that anyone familiar with the curve characteristics of a variety such as Chiefkan could easily distinguish it by means of its mixing curve, principally on the basis of its exceedingly short development time and its very marked decrease in resiliency after the maximum has been passed. Unlike Blackhull, however, this selection differs from Turkey on two qualitative scores, namely its physical dough characteristics and the inferior quality of its protein as shown by the baking test.

Summary and Conclusions

The data presented in this study support the conclusion that within a given season the potential strength of the principal hard red winter wheat varieties is related to protein content in linear fashion, and is very highly correlated with it. It has also been shown possible to obtain this expression of baking strength by means of a single formula applied under one set of fixed conditions. The formula involves the use of 2% yeast, 6% sugar, 6% dry milk solids, 0.004% potassium bromate, and 3% shortening with mixing to optimum consistency and the standard fermentation and proof times of the American Association of Cereal Chemists. When this method was used with composite samples

of Turkey, Kanred, and Blackhull, the correlation between loaf volume and protein of flour was $+$ .98.   This indicates that all but 4% of the variability of loaf volume was accounted for by variation in the protein content of the flour.

When 6% dry milk solids is used in the formula, it is possible to include sufficient potassium bromate to condition the flours of the highest bromate requirements without overdosing those of very much lower requirement.   While the function of the milk is not clearly understood, it seems evident that it creates a rather broad tolerance toward bromate, thus permitting the use of much higher increments of bromate than would otherwise be possible.

Mixing curves obtained by use of the Swanson-Working instrument reveal certain marked distinctions between variates within the hard winter wheat class as well as within varieties in the class.   Varieties such as Chiefkan exhibit such distinctive curve characteristics that they are recognizable at all protein levels.

In the opinion of the authors, the greatest usefulness of the mixing curves, provided the protein content of the flour is known, is to characterize the type to which the flour belongs.   They serve to establish *qualitative* differences between wheats that may or may not be equal in strength, and thus give an indication of the manner in which they may be expected to perform.   In many instances it is possible to make fairly good estimates of baking characteristics from a consideration of the curve.   For instance the low, broad, flat curves shown for the lower-protein range of Turkey are particularly characteristic of low-protein hard wheats, both winter and spring.   Soft winter wheats of corresponding protein content give a quite different type of curve and one that can be readily recognized.   Again, the high, broad curves of the upper protein levels of Turkey are characteristic of the strongest sample of hard winter wheats and very similar curves are obtained with high-protein samples of standard varieties of hard spring wheats. Such curves are therefore interpreted as indicating the highest strength as found in the hard types of wheat.

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STUDY OF CHECKING AND pH IN CRACKER AND BISCUIT PRODUCTS

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The first indication that crackers and cookies "check" is the appearance of very fine cracks (similar to those observed in products manufactured by the cement, ceramic, and steel industries), hardly noticeable at first but later causing the goods to break and fall apart. Checking must not be confused with tenderness.   Too tender goods may break easily like the checked goods; however, they have good chewing and eating qualities, whereas the checked goods, being brittle and tough, are deficient in these qualities.   In crackers this condition is often described as "chipsy," "chipping off," and "flinty."

Checking is treacherous because it may appear at the time of packing and then again not until the goods have reached the merchant or consumer.   In some cases, such as in army rations or when the goods are shipped to distant points, checking may not disclose itself for many months.   In any event, the checked crackers and cookies

will not stand ordinary handling and considerable breakage results in transportation.

Dunn and Bailey (1928) show several very fine photographs of checked cookies, and although their work has been of great assistance to the industry, checking is still something of a mystery despite extraordinary precautions taken in the production because it seems to appear and disappear, apparently without any reason, and particularly so under certain seasonal and climatic conditions.

The two main factors associated with checking are internal stress and brittleness. The product may resist this internal stress for many months but finally will crack because within these forces a contraction usually predominates, resulting in shrinkage. The hypothesis explaining this condition is as follows:

We may assume the flour to be the most important ingredient, and call the cracker and cookie dough a complex colloidal matter, or we may assume the other ingredients such as water, fat, etc. as more important than the flour, and call the dough (in a broad sense) an emulsion, and a dry emulsion if baked. However, we believe that checking is associated with the flour condition and that we are dealing with a highly complex colloid. If we study the matter from this standpoint, we may divide the goods made by the cracker and biscuit industry into two groups:

(1) Stable colloids—goods with no internal stress, which do not check under any conditions, nor does any other change take place.

(2) Unstable colloids—goods with internal stress. Depending upon the degree of this stress, they will check immediately after baking, during cooling, or within a few days, weeks, or months.

In working on this problem, I utilized knowledge gained in studying ceramics under Kalauner at Brno—that is, the behavior of the soil and clay (a colloidal matter) by the addition of very dilute acid and alkali. If very dilute alkali is added, the particles do not separate but stay in the suspension, whereas the dilute acid separates slowly into two distinctive phases. One is the almost clear water on the top and the other is the sediment on the bottom. In the manufacture of crackers and cookies the case is similar because of the fact that we deal also with a colloidal matter and that the chemicals [1] are added, bringing the dough to either a slightly alkaline or acid reaction. For this reason, the pH value was studied and it was found that this was one of the basic causes of checking.

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[1] In the cracker and biscuit industry, the term "chemicals" includes sodium bicarbonate (soda), ammonium bicarbonate (ammonia) and various acid bases all used as leavening agents.

Lean and Semi-lean Formulas

First, checking was studied in the goods made with a very lean formula consisting of flour and water alone with very little or no enriching ingredients, and particular attention was paid to the type of machine used in the manufacturing. It can be seen from Table I that hard breads or hard tack, water crackers, and pilot breads are made from flour and hot water mixed into a very stiff dough, and with no chemicals added they usually check because they are on the acid side as a result of the natural acidity present in the flour. Checking occurs irrespective of whether soft-winter or a blend of soft-winter and hard-spring wheat flours is used. Pilot breads, containing little enriching ingredients and only a small amount of chemicals, check as long as the chemicals are so balanced that they will bring the pH of the baked product on the acid side.

TABLE I

INGREDIENTS, pH, CONDITION OF CHECKING IN HARD-TACK, PILOT BREAD, SPRAYED, AND LUNCH MILK CRACKERS

Flour	Water	Sugar	Fat	Salt	Soda	Tartaric acid	pH	Remarks
					HARD-TACK			
100	35	—	—	—	—	—	5.8	Checking
100	52	—	—	—	—	—	6.0	Checking—made from spring-wheat flour
					PILOT BREAD			
100	35	4	7	1	0.25	0.125	6.4	Checking
100	34	4	7½	1½	0.1875	0.21875	5.8	Checking
100	34	3½	7	2	0.375	—	7.2	No checking
100	36	5	7½	½	0.50	0.25	6.6	Checking—blend with 6% of spring wheat flour
					SPRAYED CRACKER			
100	26	5	15	1	0.50	0.50	6.0	Checking
100	26	5	15	1	0.625	0.50	6.4	Checking
100	26	5	15	1	0.75	0.50	6.8	Checking
100	26	5	15	1	0.75	0.375	7.2	No checking
					LUNCH MILK CRACKER [1]			
100	25	3½	15	1	0.625	0.50	6.4	Checking
100	25	3½	15	1	0.75	0.375	7.2	No checking

[1] In the lunch milk cracker, water is replaced by whole or skim milk.

A sprayed cracker is similar to pilot bread but rich in fat. The extra added fat reduces the quantity of added water. In comparing the formulas listed in Table I, it can be seen that using two ounces less of tartaric acid (the difference between 0.50 and 0.375) per 100

pounds of flour, or 4 ounces per 200 pounds of flour, changes the pH from the acid to alkaline side.   In the alkaline medium, no checking or very little was observed.   Several years ago this cracker was made without the spraying of cocoanut oil and it used to check very badly if the pH was on the acid side.   Spraying with cocoanut oil has a stabilizing effect, but there is always the danger of checking if the cracker is on the acid side.   The other factor influencing the checking in this product is that it is made on the cutting machine in such a way that after cutting about one-third of the dough is returned and added to the fresh dough.   This procedure is repeated over and over again and this, of course, is very detrimental to the stability because although this dough is otherwise perfect, it has been subjected to the machining many times.   This of course may account for some checking even if the product is on the alkaline side.

All the baked products listed in Table I were made from unfermented doughs, being mixed with hot water so that the temperature of the doughs ranged from 85° to 115° F., and in machining they were usually put twice or oftener through the upright brake rolls, then through the sheeting rolls on the cutting machine, and later cut.   If certain precautions are taken in mixing, machining (for instance thorough perforations in cutting), and in baking, even though the product is on the acid side it may not show signs of checking for a long time.

Soda Crackers

As can be seen from Table II, acid soda crackers usually checked, but not always.   In this cracker an insufficient amount of soda was added in the dough stage and consequently the baked cracker was on the acid side.   The dough lacked elasticity and plasticity, did not run smoothly on the machine, and became short and tough.   The baked cracker took on color too quickly, having an unnatural burnt color, lacked oven spring, and was tough and brittle ("chipsy" or "flinty").   However, even the crackers on the alkaline side may check if the flours are mistreated in mixing, in fermentation (over-ripe or young sponge, or too stiff or too soft sponge, or hot sponge and dough), in machining and baking.   Crackers made from an over-ripe sponge check more than those made from young sponge.

Improper blending of flours is another cause of checking of crackers on the alkaline side—that is, if the flour blend is too soft or too strong, or if too soft or too strong flours are blended together.   The crackers made from a blend of hard-spring and soft-winter flour will check even if on the alkaline side.   In fermentation, hard-spring-wheat flours do not mature under the same conditions as those made from soft-

TABLE II

EFFECT OF pH AND FERMENTATION ON CHECKING IN SODA CRACKERS

Soda crackers	Fermentation time, in hours		pH	Remarks
	Sponge	Dough		
Alkaline	19	4	7.2	No checking
"	18	5	7.8	No checking
Acid	19	4	6.0	Checking
"	18	3	6.4	Checking
"	23	5	6.6	Checking
"	19	5	6.6	Checking
"	20	5	6.6	Checking
"	19	4	6.8	Checking
"	19	5	6.8	No checking
"	18	5	6.8	No checking
Over-ripe sponge	23	5	7.4	Checking
" "	23	4	7.0	Checking
" "	23	4	8.0	Checking
" "	22	4	7.6	Checking
Young sponge	15	5	7.4	Checking
" "	16	4	7.2	Checking
Too soft sponge	18	4	7.6	Checking
Too stiff sponge	20	5	7.4	Checking
"Hot sponge"	18	4	7.2	Checking
" "	19	3	8.0	Checking
One-hour proofing	20	1	7.8	Checking
Flour blend too soft	20	3	7.2	Checking
Flour blend too strong	20	4	7.4	Checking
Flour blend with 10% spring-wheat flour	Not known	Not known	8.2	Checking
Flour blend with 20% spring-wheat flour	Not known	Not known	7.6	Checking
Flour blend with 40% spring-wheat flour	Not known	Not known	8.6	Checking

winter wheat and crackers made of such a blend lack in fermentation flavor, have no oven spring, and are heavy. In cracker baking, blending of the hard-spring and soft-winter wheat flours is rare; however, this happens once in a while in Canada if the flour is extremely soft and where the supply of soft-winter-wheat flour is limited.

Poor baking is responsible for checking of the cracker on the alkaline side. If the heat in the oven is so balanced that the cracker does not spring as soon as it is placed on the hot oven shelf, the cracker will not rise at all during the latter part of baking. When baked it is solid and heavy. Furthermore, even a perfectly made soda cracker with pH on the alkaline side may develop a little checking because as much as 10% of the dough used has already passed machining (the

two outside strips beyond the cutting head, which are added to the fresh dough and very often not evenly distributed). This operation is very detrimental to the stability of the cracker doughs as well as the baked cracker.

In machining the soda-cracker dough passes twice through the upright brake rolls, then the sheeting rolls and the cutter on the cutting machine. In this manner the dough may be abused to a certain extent.

Cheese crackers (soda cracker with added cheese) are usually on the acid side with as low a pH as 5.0 and since cheese has a stabilizing effect, as has also the cocoanut oil which is used for spraying, there is little checking. However, under certain conditions checking may develop.

Graham Crackers

Graham crackers (listed in Table III) are not true crackers in the pure sense of the word. They are made from an unfermented dough with soda and ammonia as the leavening agents. They lean in richness toward the cookie side. Graham crackers do not check because a sufficient amount of chemicals is added so that they are decidedly on the alkaline side, and they also contain moisture-retaining substances such as honey, molasses, etc. Besides these crackers are usually baked in large sheets the size of the peel directly on the oven shelf, whereas sweet cookies are baked individually on the pans. In machining, the dough is treated in a manner similar to that used with soda crackers.

In studying the checking of cookies according to the type of machine on which they are made, the cookies may be divided into three groups: (1) wire-cut or drop and bar cookies, (2) short-bread cookies, and (3) cookies made on the cutting machine.

Wire-Cut and Bar Cookies

Wire-cut and bar cookies are made from very soft (flowing consistency) or semi-soft dough with short mixing for wire-cut cookies (until clear) and slightly longer mixing for bar cookies (little over clear). They are mixed very cool, with the temperature close to 70° F. In machining the dough is placed between the two revolving rolls and pressed through the die, and then, in the case of wire-cut cookies, cut by wire, whereas bar cookies are placed on the moving apron and cut by the knife. Because the flour in wire-cut and bar cookie doughs is not abused in mixing and machining and only fresh dough is used (no returned dough which already has passed the machine operation) and because a large amount of water is used in

TABLE III

Type of Cookie Machine, Ingredients, pH, and Condition of Checking

Type of machine	Kind of cookie [1]	Flour	Water	Sugar	Fat	Salt	Soda	Ammonia	Tartaric acid	Acid phosphate base	pH	Remarks
Wire-cut	Vanilla wafers	100	42–55	60–80	20–40	1–2	0.50–1.25	0.50–1.00	0	0	7.2–8.4	Very soft dough, no checking
"	Wafer	100	40	70	30	1	0	1.0	0	0	6.0	Acid dough, no checking
"	Jumble	100	22	50	25	1½	0.625	0	0	0.125	7.8	Semi-soft dough, no checking
Bar	Bar	100	23	45	30	1½	0	0	0	0.125	5.6	Plain acid bar, no checking
"	Cocoanut bars	100	16–18	45–55	15–20	1–2	0.50–1.0	0.375–0.25	0	0	7.0–8.0	Plain, cocoanut 25–50, no checking
"	"	100	10–14	40–45	15–20	1–2	1.0–1.5	0.25–0.375	0	0	7.2–8.2	Molasses 15–30, no checking, cocoanut 25–50
Cutting	Tea biscuit	100	14	35–45	15–20	1	0.375	0.1875	0	0	7.0	Mixed cool at 75 F., no checking
"	"	100	14	15–25	12–15	1	0.625	0.25	0	0	7.8	Mixed hot at 90°F., checking
"	Arrowroot	100	14	40	15	1	0.25	0.125	0	0	6.6	Mixed cool at 75°F., arrowroot 5–10, checking
"	"	100	14	40	15	1	0.4375	0.1875	0	0	7.2	Mixed cool at 75°F., arrowroot 5–10, no checking
"	"	100	15	30	17½	2	0.50	0	0	0	7.4	Mixed hot at 90°F., arrowroot 5–10, checking

TABLE III—Continued

Type of machine	Kind of cookie [1]	Flour	Water	Sugar	Fat	Salt	Soda	Ammonia	Tartaric acid	Acid phosphate base	pH	Remarks
Cutting	Chocolate tea biscuit	100	16	40-45	17-20	1	2.125	0	0.25	0	7.8(E) [2]	Cocoa powder 10, no checking
"	Chocolate tea biscuit	100	16	40-45	17-20	1	2.125	0	0.25	0	7.8(E)	Cocoa powder 7½, chocolate liquor 5, checking
"	Base cake	100	14	35-40	17-20	1	0.75	0.375	0	0.375	7.8	Invert syrup 5-20, no checking
"	" "	100	14	35	17	1	0.50	0	0	0.50	6.6	Acid, invert syrup 5-20, checking
"	Chocolate base cake	100	16	40-45	20	1	2.25	0	0.25	0	8.0(E)	Cocoa powder 10, no checking
"	Snap	100	15	40-55	15	1-2	0.75	0.50	0	0	8.0	No checking
Rotary	Short-breads	100	5-8	25-45	20-35	1	0.50-1.0	0.125-0.50	0	0.25-0.50	7.0-8.0	No checking
"	Chocolate short-bread	100	6-10	25-45	20-35	1	1.0	0	0	0.375	7.4(E)	Cocoa powder 5, chocolate liquor 5, no checking
"	Chocolate short-bread	100	6-10	25-45	20-35	1	1.0	0	0	0.375	7.4(E)	Cocoa powder 7½, chocolate liquor 10, checking
Cutting	Graham crackers	100	16-24	20-25	10-15	1-2	0.75-1.50	0.25-1.0	0	0	7.2-8.6	Honey and molasses 10-20, no checking

[1] Eggs may be used in the amount of 2 to 15 parts per 100 parts of flour in all except graham crackers.
[2] Electrometric.

mixing (Table III), the doughs are stabilized to such an extent that even if the cookies are on the acid side, the detrimental effect of the acid is more than counteracted and the baked cookies (being spongy in grain and porous) do not check regardless of whether they are on the acid or alkaline side.

Short-Bread Cookies

Short-bread cookies are made on the rotary machine and are usually very rich, with 20 to 35 parts of fat and with 25 to 45 parts of sugar per 100 parts of flour. Short-bread doughs are mixed for a long time at a very low speed (20 r.p.m. or lower) and so little water is added (5 to 8 parts per 100 parts of flour) that the dough is very dry and stiff and has the consistency of a paste. If the temperature is kept cool (close to 80° F.), the dough is not abused in mixing. In machining, the dough is placed between the two revolving rolls, pressed into the cups of one of the rolls, and released on the apron by another suction roll. In this operation the dough is abused very little or not at all, only fresh dough is used, and the amount of fat used is high; for these reasons the short-bread cookies do not check if they are on the alkaline side. It can be seen from Table III that chocolate short-bread cookies, made with cocoa powder and also with the combination of cocoa powder and chocolate liquor, do not check as do those made on the cutting machine. However, if the amount of chocolate liquor in the formula is too high even the short-bread pieces will check.

Cookies Made on the Cutting Machine

Sugar cookies, hard, and semi-hard sweets made on the cutting machine, such as tea and arrowroot biscuits, base cakes, and snaps, show considerable checking. In studying the manufacturing, we can see that there are many factors in mixing and machining favoring checking. Mixing is carried on too far (overclear) and the dough becomes tough and is able to take up the returned dough which has already passed machining. The amount of this returned dough is sometimes more than the fresh dough, that is, about two-thirds in small pieces with a count per pound of 100 to 150 and about one-third in the larger pieces with a count per pound of 50. In machining, the dough passes through one to four sheeting rolls and then is cut. After cutting, the dough lying between the cookies and that on the edges beyond the cutting head is returned and mixed with the fresh dough. It can be seen that mixing and especially machining produce a very unfavorable condition for the stability of the dough and for that

reason many cookies made on the cutting machine will check even though they are on the alkaline side.

Baking and Cooling

Checking due to improper baking may occur if too hot an oven or "flash heat" is causing excessive rising and little spreading ("poor") in the goods, or too cool an oven or lack of heat is causing excessive spreading and little rising ("rich"). It can be seen that from the same dough three kinds of cookies can be baked: that is, on the "poor" and "rich" side and with the correct shape and weight.

Checking may be due also to underbaking caused by the present high-speed production with fast baking, and in rare cases it is due to overbaking caused by baking too long a time at low temperatures (resulting in more drying than baking).

On the whole, pH has a profound effect on baking. At the present time with high-speed production, baking is carried out only to the certain desirable color. In baking the acid products, especially with pH 6.0 or lower, take up color so quickly that to prevent burning the products must be taken out from the oven underbaked, whereas the alkaline products with pH 8.0 or higher also take up color quickly with a thick crust formation but not so fast as the acid products. To assure thorough baking, both acid and alkaline products should be baked at lower temperatures for a longer time. There is no doubt that both acid and alkali affect the caramelization of the starch and sugar at baking temperatures, causing the goods to take up color so rapidly that they appear well baked when they are actually raw and underbaked. In baking, best results are obtained with pH at 7.0 (neutral) or slightly on the alkaline side with pH below 8.0, because then the product may be thoroughly baked, and the color will be derived chiefly from the ingredients used in the formula—thus the undesirable coloring effect of the acid and alkali is eliminated.

To prevent chilling, which causes checking, during cooling, two methods are employed: (1) Fast cooling so that the goods are packed hot, which condition is favorable for sogginess and rancidity. Also, cooling is accomplished in such a short time that checking has not as yet taken place but may occur later in the package. (2) Gradual or slow cooling so that the goods are packed warm but not hot. This, if properly done, should give much better results than fast cooling not only from the checking but also from the quality standpoint.

Formulas

Checking may occur (1) if the flour used is too soft, too strong, or a blend of too soft and too strong and if no attention is paid to the

changes caused by the new crop flours; (2) if not enough or too much sugar is used, causing the goods to be on the "poor" or the "rich" side, particularly so when on the "poor" side; (3) if the chemicals act in the oven in such a way that the action of "raising" and "spreading" is not balanced.

Even with well balanced formulas, the chocolate cookies made on the cutting machine with cocoa powder or with the combination of cocoa powder and chocolate liquor show a great tendency to check even if high on the alkaline side. It can be seen that cocoa powder and especially chocolate liquor produce conditions very unfavorable for the stability of the dough.

Effect of the Acids

An acid medium has a very unfavorable effect on dough development, causing it to become too tough with a great deal of decrease of elasticity and plasticity. The effect of acids may be disastrous if acid-reacting ingredients such as unneutralized invert syrup, honey, and molasses are mixed with flour before the soda is added, which is usually sifted last on top of the flour. In such a case the dough may become so tough that it does not retain the round shape stamped by the cutter but is deformed into an oblong shape. The round and uniform shape is very important in base-cake cookies made for sandwich and marshmallow pieces. The pH of such deformed cookies may be on the alkaline side because a sufficient amount of soda was added to bring it to this point, but the damage was done in mixing prior to the addition of the soda. In such a case, soda is not able to restore the dough to its natural condition but is at least able to prevent checking. Naturally, the dough not containing invert syrup, etc., may become too tough in mixing if chemicals are not well balanced and the pH is brought to the acid side. The toughness is caused by the acid portion of the chemicals and as can be seen from Table III such cookies check.

General Remarks

Glycerine, invert syrup, and invert syrup containing ingredients such as honey and molasses, used as preventive measures against checking, have a stabilizing effect. Spraying with cocoanut oil has a similar effect.

Because goods on the acid side are brittle, easily broken, and check readily, a shortometer has very little value for determining the shortness of this type of product. In the products on the alkaline side, the shortometer may be of value if the tested samples have, or are brought to, the same pH value, provided they do not check.

Bohn, Gilner, and Kinder (1936) have shown that the alkalies are very detrimental to flavors such as pure vanilla extract, lemon oil, etc., and to conserve these flavors the pH should be kept on the acid side. On the other hand, our work has shown the detrimental effect of the acids, and it can be seen that the only compromise possible is to keep the pH at 7.0 (neutral) or very close to it. Soda has a very beneficial effect on the elasticity and plasticity of the doughs, if used in quantities to bring the pH slightly on the alkaline side (below 8.0). In the past this practice was overdone to a great extent and larger quantities of soda were used, bringing the pH as high as 9.0. With a pH over 8.0 not only are most of the added flavors destroyed but the product has a soapy aftertaste, probably due to a slight soap formation at baking temperatures by the reaction of soda and fat.

The pH determinations were made by the colorimetric method, and only in the chocolate pieces by the electrometric method. The colorimetric method is used extensively for checking production in the cracker and biscuit industry and appears to give better results because it shows well the excessive amount of soda used in the formula, giving slightly higher results.

Summary

Checking in cracker and biscuit products is associated with the flour condition and is caused by internal stress and brittleness.

The governing factor is pH, not only in checking but in the whole process of manufacturing, that is, in mixing, machining, and baking, as well as in the quality of the finished product.

A pH on the acid side is responsible for checking and for the unstable condition of the doughs, causing them to become tough with a decrease of elasticity and plasticity.

A pH slightly on the alkaline side is responsible for the increase of elasticity and plasticity of the dough, causing easier machining with no checking in the finished product. However, if the flour is mistreated in mixing, fermentation, and machining, or if there is improper baking (particularly underbaking), cooling, or an unbalanced formula, checking may occur.

In soda crackers, a blend of soft-winter and hard-spring wheat always causes checking.

Returned dough, cocoa powder, and especially chocolate liquor have a very unfavorable effect on the stability of the doughs, causing checking even if the product is on the alkaline side.

High absorption and high shortening content have a favorable effect on the stability of the doughs with a tendency to prevent checking.

In order to maintain the quality of the finished product, to insure smooth and easy machining, and to prevent checking, the pH should be kept close to 7.0 or slightly on the alkaline side.

The shortometer cannot be used for measuring the shortening value of the crackers and cookies if they are checking.

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STANDARDIZATION OF THE SCORING OF TEST CAKES [1]

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(Read at the Annual Meeting, May 1939)

Previous sub-committees on Methods of Testing Cake Flours have expressed the need of a more systematic and standardized method of scoring the test cakes made by the present tentative A.A.C.C. method. The chairman for the 1938–39 committee assigned to the author, as a member of the committee, the task of preparing some photographic standards for the grain scores. The work was carried somewhat further, resulting in some recommendations for a standardized system for other cake scores. The series of pictures finally selected represent the composite opinion of all the committee members, and other scoring methods suggested in this report are presented here with the committee's approval.

The methods of scoring which will be presented apply only to cakes made by the present tentative A.A.C.C. formula as described in *Cereal Laboratory Methods*. The scoring system according to the present A.A.C.C. method includes the following characteristics and points for perfect scores:

A—External		B—Internal	
Symmetry	10	Texture	
Volume	15	Tenderness	15
Crust	5	Silkiness	15
		Grain	25
		Color	15

The cake scores which tell much about the flour are those on volume, symmetry, and grain. These scores can be standardized

quite satisfactorily, while scores such as those on tenderness and silkiness must be based on the operator's personal judgment.

Volume Score

The perfect volume score is 15 according to the A.A.C.C. scoring system. Previous committees on collaborative testing of cake flours with the A.A.C.C. formula have shown no uniformity in assigning this score. Last year, one operator gave a score of 5 for a cake volume of 790 cc.; another gave a score of 16, one better than perfect, for 804 cc.; and another 8 for 833 cc., and so on. Instead of such irregularity in assigning the volume score, it would be much better to use a systematic scale.

There are several methods which at first appear to be logical as bases for a volume scale. First, the score could be based on the specific volume of the cake, but previous committee work has shown that the baking loss varies considerably in different laboratories, and would thus produce differences in the specific volumes. Second, the volume increase of the batter could be used, but this would require the determination of the specific volume of the batter, and the values obtained would have little meaning. Therefore the actual volume of the cake in cubic centimeters as a basis for the score is by far the simplest and the best method and involves only one value and no calculations.

The standard test requires the use of 325 g. of batter, and with the best of cake flours now available and with the present test formula, the cake volume will seldom exceed 940 cc., but cakes with volumes from 925 to 940 cc. have been obtained. After consideration of numerous factors in connection with the volume score, the following scale was decided upon by the committee for use with 325 g. of batter:

Cake Volume (cc.)	Score		Cake Volume (cc.)	Score
940-920	15		780-760	7
920-900	14		760-740	6
900-880	13		740-720	5
880-860	12		720-700	4
860-840	11		700-680	3
840-820	10		680-660	2
820-800	9		660-640	1
800-780	8		<640	0

Some laboratories probably prefer using 350 or 375 g. of batter, but proportional scales can easily be calculated since within these limits the cake volume is practically proportional to the batter weight. This system of scoring the volume should be much better than the previously used random method, although cake volumes obtained vary as much as 100 cc. for test cakes made in different laboratories and from the same ingredients. This variation appears to be due primarily to the technique used, which should be further standardized.

Grain Score

Numerous actual-size pictures were made of the interior of cakes and circulated among committee members, and the series of pictures finally selected represent the composite opinions of the committee members. Figure 1 shows a smaller reproduction of the actual-size
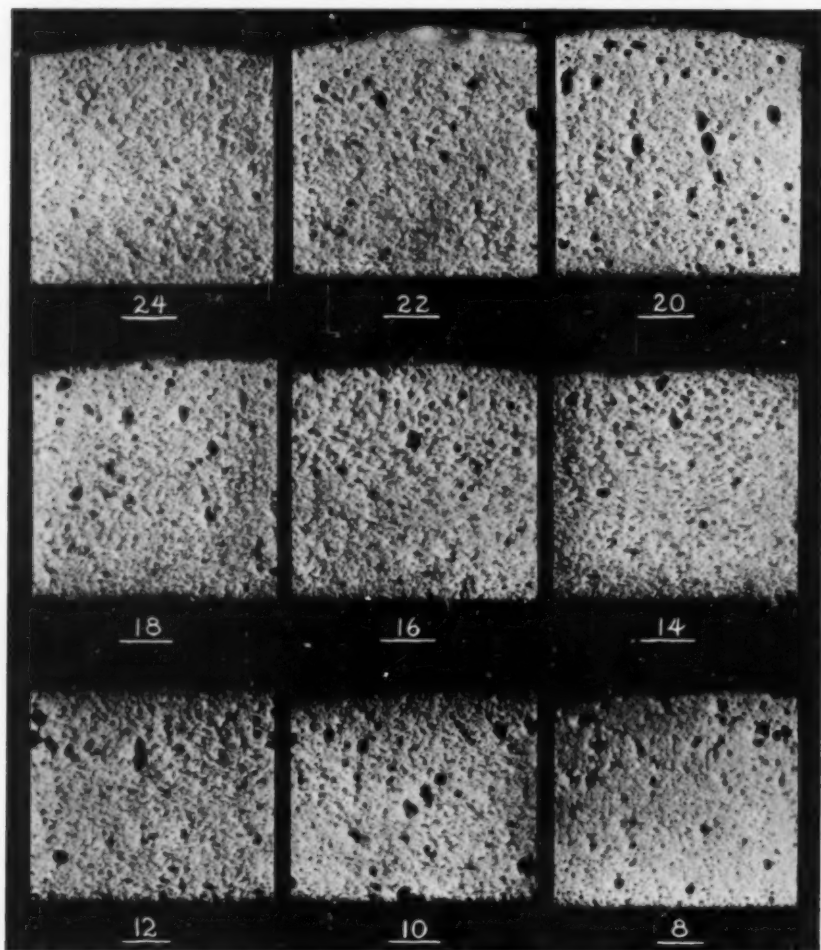
Fig. 1. Reproduction of the photographic grain standards.

picture series. The perfect grain score is 25, but it is quite difficult to produce the perfect grain, and hence that was left for extrapolation, and the best grain pictured was given the score of 24. As the scores go down from 24 to 22 and so on the cell walls become increasingly thicker and the grain coarser. Any cake which appears to match one of the standards except that it has more holes or channels can be assigned the next-lower odd score. These pictures should help some-

what in standardizing the grain scoring and should especially be an aid to inexperienced operators.

Symmetry or Shape Score

The symmetry score actually refers to the shape of the cake as observed after it has been cut lengthwise.   A high top or very convex cake will be scored low, although the cake may be perfectly symmetrical, and this score should more properly be referred to as shape.
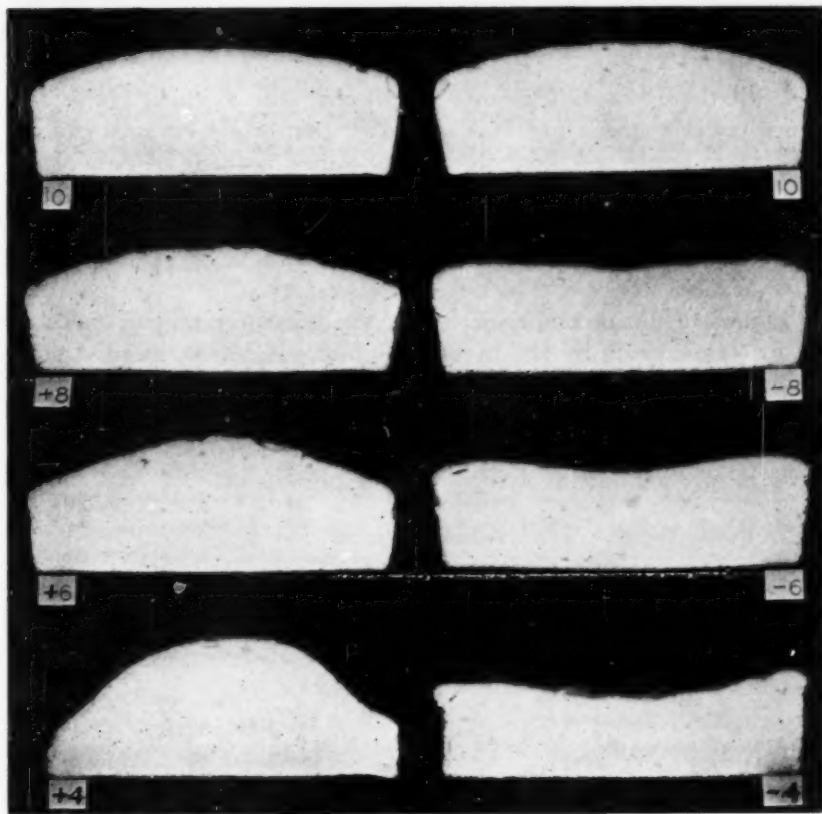
Fig. 2.   Standards for the scoring of symmetry or shape of the test cakes.

This score has also been based entirely on the operator's opinion and without any standard guide.   The shape of the cake is quite indicative of the cake-flour quality.   A stronger-protein flour will give a more rounded convex top, while a weaker flour or a flour with low sugar or shortening tolerance will give a flat or concave top.

Figure 2 shows a series of test cakes cut lengthwise and with different shapes.   The two top cakes have been given the perfect score of 10, and they have slightly rounded tops with only slight breaks.

They appear to be the shape of cake obtained by good cake flours with the present formula. It is further suggested that a simple plus or minus sign precede the numerical score on the score card for convex and concave cakes, respectively. While the extreme of one type is as detrimental as the other type, the numerical scores may be the same but the type of symmetry or shape would be indicated by the plus or minus sign. The concave cakes are especially obtained when supplements A and B of the A.A.C.C. formula are used, namely the sugar and shortening tolerance tests, respectively. The odd scores are left for interpolation of cakes which appear to come between the pictured standards.

With these possibilities of standardizing the volume, grain, and symmetry or shape scores, it is suggested that scores for such characteristics as tenderness and silkiness be varied as little as possible as long as they are based entirely on personal judgment. The volume, grain, and shape scores alone will probably classify cake flours with the formula now used, and the scoring would be more uniform in different laboratories and by different operators.

It must again be emphasized that the presented scoring methods are for cakes made by the present tentative A.A.C.C. method only, and will not apply to cakes made from other formulas. This is particularly true for the grain standards and the volume scale. If in the future the test formula should be changed, new standards could easily be worked out involving the same principles.

Acknowledgment

Photographs

A set of the two photographs for grain and shape can be purchased during years 1939 and 1940 for 75 cents from the Photographic Laboratory, University of Minnesota Farm Campus, St. Paul, Minnesota.

STARCH AS A FACTOR IN DOUGH FORMATION [1]

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Starch constitutes the major part of wheat flours and during recent years has been subjected to considerable study in relation to flour quality, enzyme susceptibility, and bread staling. Wheat-starch granules vary in size and Grewe and Bailey (1927) grouped the granules as small, medium, and large and determined the percentages by number of these groups in 17 flours. They concluded that there was no relation between the size distribution of the granules and the baking results. Buchanan and Naudain (1923) grouped the granules as below or above 7 microns, and from a study of seven flours concluded that strong flours have the largest percentage of small granules, but they considered the average size more important. They did not give the protein content of the flours used, and they based their conclusions regarding flour strength on loaf volume and grain. Naudain (1925) from a study of four flours found the baking results were poorer in the flours with a higher percentage of large starch granules.

Some studies of flour strength have been made by diluting flours with starch. Jago (1911) added 20 parts of potato, wheat, or maize starch to 80 parts of flour and observed that with added starch the baking results were poorer, and that the absorption was greater for the maize mixture than for the potato mixture. Johnson and Bailey (1925) found that the addition of starch to flour reduced the gas retention of the dough, but the gas production was not impaired. Alsberg (1935) suggested that starch may also play an important role in the variability of absorption of flours, and Pulkki (1938) found that a reduction of the flour-particle size increased the absorption appreciably, as a result of an increase of injured starch granules.

Markley (1938) diluted flours with wheat starch to various protein levels and studied the absorption necessary to produce doughs with a minimum mobility of 550 farinograph units. At about 7% to 8% protein (13.5% moisture) the minimum absorption was observed and the mixed flour-starch blends below this protein level had the physical characteristics of a starch paste rather than a dough. Markley suggested that with less than 7% protein there was not enough protein or gluten to cover the surface of the starch granules and hence the mixed blends below this protein level had the characteristics of starch pastes. The work reported here includes some further studies of the

[1] Paper No. 1720, Journal Series, Minnesota Agricultural Experiment Station, University of Minnesota, St. Paul.

relationship of starch surface area to absorption and protein films in doughs.

Starch-Granule Distribution in Flours

With the data of Grewe and Bailey (1927) available on the distribution of various sizes of starch granules in 17 flours, it is possible to calculate quite accurately the starch surface areas of these flours. They measured the starch granules under a microscope on the ruled hemocytometer slide and classified the granules as those with a diameter of less than 7.4 microns, those from 7.4 to 14.8 microns, and those of a diameter greater than 14.8 microns. About 700 granules from each flour were measured, and the percentage by number of each size group was determined. After some observations of wheat-starch granules under the microscope, it was decided, for purposes of calculation, to use an average diameter of 4.7 microns for the small granules, 10.1 microns for the medium-size granules, and for the large granules an average diameter of 24.9 microns. A value of 1.5 was used as the density of starch. Actually wheat-starch granules approach the shape of oblate spheroids, but for the calculations a spherical shape was assumed, which should give fairly accurate values.

In Table I the calculated surface areas in square centimeters per gram of starch are given for the 17 flours. The relative starch surface areas of the flours are also given in percentages based on the average surface area. The types of wheat used as the source of the flours are also included, as given by Grewe and Bailey, and their percentages by number of the small granules. There is a close relationship between the percentage of small granules and the surface area, which of course would be expected. The flours used by Grewe and Bailey were mainly high patent flours and different results might be obtained with other grades.

The variation in surface area was from 88.8% of flour No. 3 to 116.7% of flour No. 14, as based on the average surface area of the 17 flours, taken as 100%. Twelve of the flours were within the 12% variation or from 94% to 106% of the average, with the remaining five flours falling outside this range. The possible significance of this variation in surface area will be discussed subsequently.

Figure 1 shows graphically the distribution of the three sizes of starch granules according to number, weight, and surface area per unit weight. The values were based on the average of the 17 flours. It is evident that the large-granule fraction predominates as far as weight and surface area are concerned, and that the large granules constitute the major portion of the wheat starch and also account for most of the surface area of the starch in wheat flours. One gram of small granules with an average diameter of 4.7 microns would have

TABLE I

STARCH SURFACE AREAS OF VARIOUS FLOURS [1]

		Calculated	
Wheat used for flours	Percent by number of small starch granules	Starch surface area in cm^2/g of starch	Percent relative starch surface area based on average value
1. Pacific soft white	80.45	1943	97.0
2. Canadian spring	86.36	2079	103.6
3. Hard spring	59.97	1780	88.8
4. Hard winter	75.03	1912	95.4
5. Canadian hard spring	85.92	2018	100.7
6. Hard red winter	79.84	1908	95.2
7. Ohio soft winter	76.65	1802	89.9
8. Indiana soft winter	88.16	2106	105.1
9. Minnesota hard spring	77.94	1904	95.0
10. Minnesota hard spring	79.07	1915	95.6
11. Minnesota hard spring	83.01	2053	102.4
12. Minnesota hard spring	89.55	2220	110.8
13. Ohio red winter	87.78	2160	107.8
14. Nebraska hard spring	91.79	2339	116.7
15. Missouri soft winter	82.80	1965	98.1
16. Montana hard winter	74.39	1840	91.8
17. Durum	87.77	2120	105.8
Average	—	2004	100.0

[1] Calculated from data by Grewe and Bailey (1927).
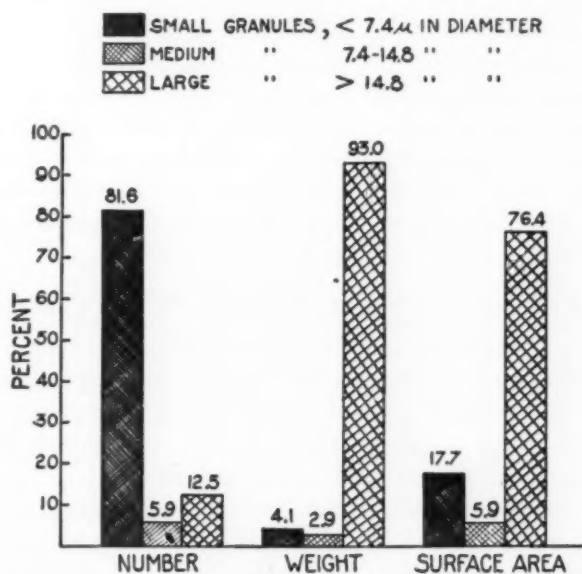
Fig. 1. The distribution of the small, medium, and large starch granules in flours according to percentages by number, weight, and surface area, and based on the average values of seventeen flours.

a surface area of 8,519 cm.^{2} per gram, and the large granules with an average diameter of 24.9 microns a surface area of 1,606 cm.^{2} per gram.

Absorption of Flour-Starch Mixtures

Markley (1938) found that on diluting flour with wheat starch a minimum of the absorption curve occurred at about 7% to 8% protein, with a change from a dough to a starch-paste system below this protein level. If this change were due to an increase of the total starch surface area to the extent that the protein content becomes too low to form a continuous film or reticulum, it would be expected that by using starches of various sizes this change would occur at other protein levels. To test this assumption a series of absorption tests were made by diluting a flour with rice, corn, wheat, and potato starches, and also finely pulverized wheat starch.

A flour with 11.14% protein (15% moisture) was used. Flour-starch blends were mixed in the farinograph and the absorption adjusted to give a minimum mobility of 500 units. Two percent salt was used in all doughs. The absorption values obtained were on the basis of 15% moisture, and the amount of starch added is indicated by the protein content of the mixture.

Figure 2 shows the absorption curves obtained by diluting the flour with the various starches. Rice starch, having the smallest granules, produced a minimum absorption at about 10% protein, corn starch at 8.5% protein, wheat starch at 7.5% protein, and the larger potato-starch granules at 4.3% protein. Thus the minima of the absorption curves are in the same relative order as the size of starch granules used, indicating a relationship between starch surface area and the observed minima. Addition of wheat starch which had been ground to fragments in a rod mill increased the absorption considerably above that of the unground wheat starch, and broken starch granules undoubtedly play an important role in the absorption of flours.

Starch Surface Area in Relation to Protein Content

To study further the relationship of the starch surface area to the absorption and to the protein content, the surface areas of the flour starch and the starch samples used were determined by measuring the granules under a microscope and then calculating the surface areas per gram by the method previously explained.

The rice-starch granules were from 4 to 8 microns in diameter and within a fairly uniform size range. The corn-starch granules varied from 8 to 18 microns in diameter. The potato-starch granules showed a wide size distribution and were classified in groups of below
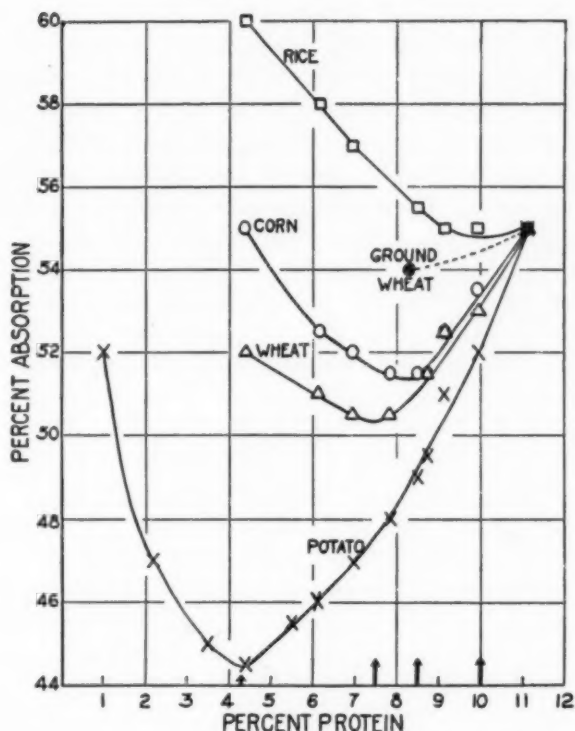
Fig. 2. The relationship of the absorption necessary to give doughs of a minimum mobility of 500 farinograph units to the protein content, upon dilution of a flour with various starches.

25 microns, 25 to 50 microns, and above 50 microns in diameter. The calculated surface areas per gram of starch are given in Table II. The approximate ratios of the surface areas per unit weight of the starches were 1, 2, 3, and 8 for potato, wheat, corn, and rice, respectively.

With the starch surface areas per gram known for the flour and the starches, it was possible to calculate the change in surface area as the flour was diluted with the starches. Figure 3 shows the change in starch surface area in square centimeters per 100 grams of flour-starch blends (15% moisture) in relation to the protein content.

In Figure 3 the slight increase in surface area upon dilution with wheat starch was due mainly to the increase in the amount of starch per 100 grams. With the other starches the change in surface area was primarily due to granule size. The potato starch produced an immediate rapid decrease in surface area, while the corn and the rice starches increased the surface considerably.

From the graph in Figure 3, the starch surface areas can be obtained at the protein levels corresponding to the minima of the absorption

TABLE II

Starch Surface Areas

Starch	Calculated total surface area of the starch samples	Approximate ratios of total surface area per unit weight
	cm^2/g	
Flour starch	1974	
Potato starch	853	1
Wheat starch	1907	2
Corn starch	3077	3
Rice starch	8000	8
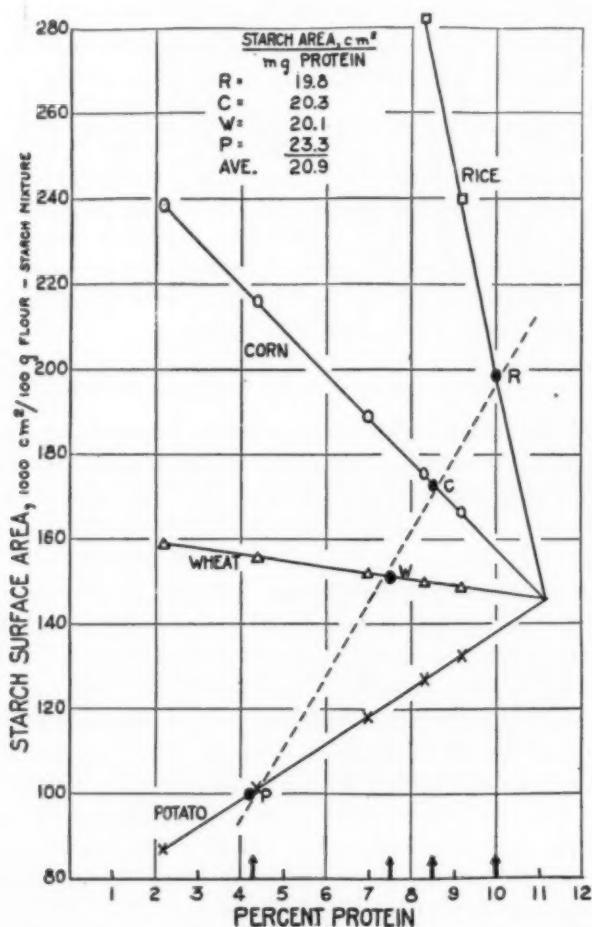
Fig. 3.   Total starch surface area per 100 grams of flour-starch mixtures (15% moisture) at the various protein levels.   The arrows along the abscissa are at the points corresponding to the minima of the absorption curves in Figure 2.

curves in Figure 2, namely at 4.3, 7.5, 8.5, and 10.0% protein respectively for the potato, wheat, corn, and rice starch curves. These points are shown at R, C, W, and P, in Figure 3. The ratios of starch surface area in square centimeters per milligram of protein (cm.^{2}/mg.) at points R, C, W, and P were found to be 19.8, 20.3, 20.1, and 23.3, respectively, with an average value of 20.9. These values check so closely that they indicate quite definitely that in flour-water doughs mixed to the stage of minimum mobility the protein film envelops each individual starch granule. If this were not so, the ratios obtained by the various starches should not be constant since they were obtained on the basis of starch surface area.

The hydrogen-ion concentration is an important factor in studies of proteins, and the flour used had a pH of 5.74. With mixtures of half flour and half starch the pH values were 5.00, 5.72, 5.72, and 6.28 for rice, corn, wheat, and potato starch, respectively. The variations in pH of the rice and the potato starch may account to some extent for the greater deviation of the cm.^{2}/mg. ratios as compared to those of corn and wheat starch. Furthermore, the potato-starch granules were rather irregular in shape, and it was quite difficult to estimate the mean diameter.

The results indicate that in accordance with Markley (1938) the protein content of the flour must be over 7.5% for dough formation. With 7.5% protein at 15% moisture the amount of starch would be about 75% or on a dry basis the ratio of protein to starch must be greater than 0.1 for dough formation. There still remains a possibility that this cannot be taken as an absolute value under all conditions. If a different mixer were used with a more severe mechanical action than the farinograph, the possibility is that the break in the absorption curve would come at a higher protein level or at a thicker protein film.

Starch as a Factor in Absorption

The data in Table I show that most of the flours included were within a 12% range of variation in surface area. Through the difference in absorption at the same protein level of any two absorption curves in Figure 2 and with the corresponding difference in surface area available from Figure 3, it was possible to estimate that with a 12% difference in starch surface area there would be a difference of 0.9%, or about 1%, in the absorption. Since the maximum variation in starch surface area of the 17 flours studied was as high as 27%, it appears that a variation in absorption due to surface area may be 2% but in the majority of cases probably is 1% or less. In addition to the starch surface area, the number of broken starch granules in a

flour is an important factor related to the absorption, as can be seen by the addition of ground wheat starch. This is in agreement with Pulkki (1938) that overgrinding of flours increased the absorption as a result of broken starch granules.

The absorption so far discussed has been in relation to a constant minimum mobility of 500 units in the farinograph. The absorptions required for best baking results with flours of various protein contents are probably different, according to Merritt and Bailey (1939), whose results indicated that low-protein flours gave best baking results at lower minimum mobilities than 500 farinograph units and high-protein flours at higher mobilities than 500 units.

A low-protein flour mixed to 500 farinograph units will feel firmer to the operator than a high-protein flour mixed to the same consistency in the farinograph. An instrument which will measure this firmness of the dough will probably give a better indication of the proper absorption required for best baking results. Here again the starch plays an important role since this firmness of doughs made from low-protein flours is undoubtedly due to the thinner gluten films separating the relatively hard starch granules. In the farinograph this firmness is apparently not distinguished from the softer but more tenacious doughs of high gluten contents.

The Protein Film in Doughs

From the data and the discussions in the previous paragraphs it appears that, in doughs mixed to the stage of minimum mobility from flours with 7.5% protein or more, the protein reticulum envelops each individual starch granule. Assuming the proteins in a dough as a uniform anhydrous film around the starch granules, and with the average spreading value of the protein established as 20.9 cm.^{2} per milligram at the 7.5% protein level of the flour, it is possible to calculate the thickness of such an assumed anhydrous film. With the density of anhydrous proteins as 1.3 (Neurath and Bull, 1938) the thickness of this film was calculated as 3,684Å. Much of the work on monomolecular protein films has been with egg albumin, but Neurath and Bull (1938) in a review article quote data for gliadin as having a monomolecular film thickness of 4.5Å at zero pressure and about 15Å at high pressures, and the thicknesses of various other monomolecular protein films are in the neighborhood of 10 to 12Å. Hence the assumed anhydrous protein film around the starch granules in a dough made from a 7.5% protein flour would be equivalent to about 350 monomolecular protein layers thick, and the thickness of the film between two starch granules would be about twice that amount. As the protein content of the flour increases above 7.5%

this assumed film thickness will increase proportionally. Actually the hydrated proteins or the gluten film in a dough is much thicker and is extended into a much larger volume than that of the assumed anhydrous film, and hence the values arrived at are only speculations.

There is no direct evidence, however, that in a dough the starch granules are surrounded by successive orderly arranged layers of monomolecular protein films, and a more disorganized or brush-heap structure of the protein micelles has often been discussed. The fact seems to be that on mixing flour and water into a dough a rearrangement of the proteins around the starch granules takes place concomitantly with a hydration of the proteins until the stage of minimum mobility of the dough is reached. When this stage is reached the dough will perform most satisfactorily from the standpoint of baking results. Stamberg and Bailey (1938) showed that the amount of work in watt hours necessary to complete this process of mixing and hydration increased with the protein content, and in the farinograph the required mixing time was longer with higher percentages of protein.

Some additional work has been done on protein films in milk doughs and the indications are that milk proteins will supplement to some extent the flour proteins in forming a protein film or gluten in a dough, but since it makes the picture of protein films more complex it will not be included in this discussion.

Starch and Flour Strength

Flour strength is a term which is used in relation to many flour factors such as protein quantity and quality, absorption, diastatic activity, and the tolerance to mixing and fermentation processes, with the ultimate criterion being the quality of bread produced. Starch plays an important role in many of these factors. The differences in enzyme susceptibility of wheat starches and the effect of these differences on diastasis and fermentation have been studied by many investigators. In relation to absorption the variation in starch-granule size must be considered, as well as the number of injured starch granules.

The starch-granule size and surface area seem to be of importance in relation to the protein film in a dough and hence probably to flour strength. Buchanan and Naudain (1923) and Naudain (1925), using loaf volume and grain as the criteria, concluded that strong flours had the largest percentage of small granules, as the result of a study with just a few flours. Grewe and Bailey (1927) in a study of 17 flours concluded that the starch-granule size variations could not be correlated with any of the baking test results. Spaeth (1915) concluded that the percentages of small starch granules were higher in

weak flours, and that the quantity of small granules depended upon soil and climatic conditions.

Let us suppose that two flours have the same protein content and one of them has a higher than average percentage of small granules, then in a dough made from the latter the protein films would be thinner and might be expected to simulate the film from a lower-protein flour with average-size starch granules. With this reasoning, it seems that a large percentage of small granules would result in a poorer baking quality, with all other factors equal. On the other hand, a high percentage of small granules would give a closer packing of the starch granules with a finer structure of the dough. During the baking process in the oven the small granules will resist swelling and gelatinization until a higher temperature is reached (Naudain, 1925; Alsberg, 1926) and the dough would have a longer period for oven expansion due to the slower gelation of the starch and setting of the dough. These and perhaps many other opposing factors are involved and it is difficult to postulate the variation in baking quality of flours due to starch-granule size variations.

Further work appears justified on the starch-granule size distribution in flours of different varieties and from wheats grown under different conditions. It is not possible with the information now available to state definitely that starch-granule size variations are of importance to any factor other than the absorption of flours, but baking quality and the rate of bread staling may be related to the granule size distribution.

Summary

The surface area per gram of wheat starch based on the average of 17 flours was calculated as 2,004 cm.^{2} The flours showed a variation of surface area of from 88.8% to 116.7% of the average surface area, but twelve of the flours were within a 12% range of variation or within 94% to 106% of the average.

In terms of numbers the small starch granules, below 7 microns in diameter, represent 31.6%, but in terms of weight or total surface area the large granules, above 14.8 microns in diameter, are by far the most important and represent 93.0% by weight and 76.4% of the total surface area.

The surface areas per gram of commercially prepared potato, wheat, corn, and rice starches were found to be 853, 1,907, 3,077, and 8,000 cm.^{2}, respectively, or in approximate ratios of 1, 2, 3, and 8, respectively.

Upon dilution of a flour with the various sizes of starch granules, the absorptions necessary to produce doughs of a minimum mobility

of 500 farinograph units at various protein levels were determined. The minima of the resulting absorption curves were at different protein levels when the various starches were used.　By calculating the starch surface area per milligram of protein at these minima the values were 19.8, 20.3, 20.1 and 23.3 cm.^{2}, for the rice, corn, wheat, and potato starch curves, respectively, with an average value of 20.9.　Thus the starch surface area was found to be the factor involved at the minima of the absorption curves.

It was concluded that for dough formation in the farinograph mixer the protein content of a flour must be over 7.5% (15% moisture), or on a dry basis the ratio of flour protein to starch must be greater than 0.1.

It was calculated that the variation in starch surface area, as far as the 17 flours studied disclosed, can effect a variation in the absorption of as high as 2%, but with the majority of the flours this would be 1% or less.　Injured starch granules were observed to increase the absorption appreciably and may be of most importance.

Some estimations of the thickness of protein films in doughs were made on the basis of the thickness of monomolecular protein films, and in doughs made from 7.5% protein flour, the minimum for dough formation, the protein film was estimated to be some several hundred protein molecules thick, with the thickness of this film increasing with a higher protein content of the flour.

Further work is suggested on the possibility of a relationship of flour strength and baking quality to the starch-granule size distribution in flours of various grades and from different sources, since the information now available is incomplete and conflicting.

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STARCH IN RELATION TO SOME BAKING PROPERTIES OF FLOUR[1]

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(Read at the Annual Meeting, May 1939)

In general the idea prevails that the baking properties of a flour are determined chiefly by the quantity and characteristics of its gluten and that possible differences in the starch are of minor consequence. Alsberg (1935) stated that "with fuller knowledge, it may appear that variations in the properties of the starches of different flours influence baking quality materially." In flour it is exceedingly difficult to differentiate those baking characteristics which belong with the starch from those which belong with the gluten, since any treatment applied to the flour might conceivably affect either or both.

The addition by Morea (1937) and by Aitken and Geddes (1938, 1939) of crude gluten to a dough to increase its protein content and thus enhance its baking properties suggested the possibility that gluten and starch might be combined to form a "synthetic" dough which could reflect the individual properties either of the starch or of the gluten from which it was made. A synthetic dough of this type could afford a basis for the study of differences in some of the individual constituents of flour and for a study of their properties in relation to baking behavior. It might also provide an opportunity to study the effects of various flour treatments on these individual constituents and the effect of the treatment on the baked loaf.

The first attempts at combining gluten and starch in a synthetic dough were made with wet crude gluten and commercial wheat starch, but this combination baked into a very inferior loaf of bread. This suggested a possibility that either the water-soluble constituents (lost in washing the gluten) were essential to the production of a good loaf

of bread, or that the commercial starch had been altered by some
procedure in its preparation.

Accordingly fresh wheat starch was prepared by centrifuging the
water suspension of starch obtained in washing gluten.   Two distinct
layers of material separate from the liquid in the centrifuge tube.
Figure 1 shows centrifuge tubes containing the starchy material from
50-g. portions of different flours.   The lower layer is relatively pure
starch which contains about 35% of water and on the dry basis 0.3%
of protein and 0.1% of ether extractable lipoid.   The upper gelatinous
or semi-liquid layer seems to be the impure, highly hydrated "dextrins"
resulting from the action of the flour amylases on the "available"
starch.   It contains 80% to 90% of water and on the dry basis, along
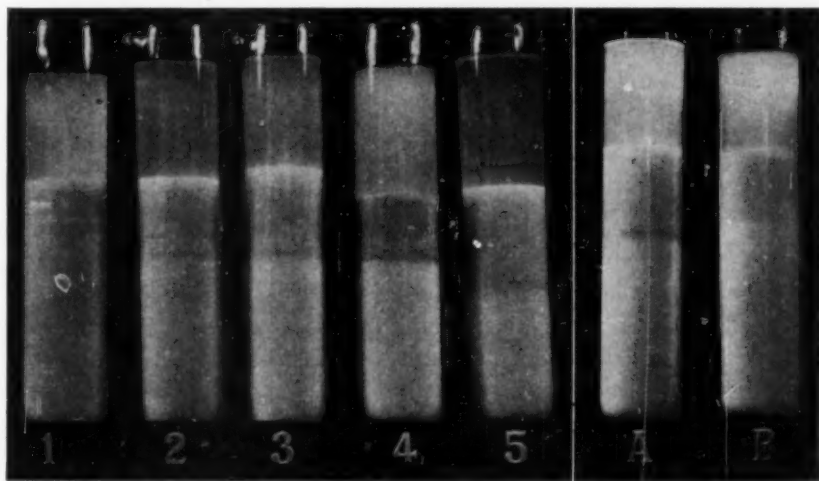
Fig. 1.   (Nos. 1 to 5 at left.)   Starch and amylodextrin fractions from different flours.
Fig. 2.   (A and B at right.)   Starch and amylodextrin from flour and middlings.

with some unidentified material, about 3% of protein ($N \times 5.7$) and
0.5% of ether soluble lipoid.   The characteristics of this "dextrin"
material are quite similar to those of the "amylodextrin" material
which remains after the action of beta-amylase on boiled wheat starch
(or on wheat starch which has been ground in a ball mill until the
granules are completely ruptured).   Since much of this fraction is
apparently derived from the available starch by the action of beta-
amylase, it is tentatively designated as amylodextrin.

Tube No. 1 (Fig. 1) contains the amylodextrin and starch cen-
trifuged from 50 g. of an Oregon soft-wheat flour (protein 7.5%);
No. 2 from experimentally milled 85% patent flour (protein 12.5%);
No. 3 from 85% baker's patent flour (protein 12.5%); No. 4 from
clear flour (protein 14.1%); and No. 5 from durum flour (protein

13.8%).   The flour represented by No. 2 was experimentally milled
from a sample of the same wheat mix from which the flour represented
by tube No. 3 was milled.   It will be noticed that the ratio of amylo-
dextrin to starch increased with the hardness of the wheat from which
the flour was milled, that is, from soft wheat to hard wheat to durum.
This increase in amylodextrin with increase in hardness may be an
inherent characteristic of the starches as they occur in the wheats, or
it may indicate that the ratio of amylodextrin to starch increases
with the severity of the milling.   This latter hypothesis is substan-
tiated by the smaller amount of amylodextrin obtained from the
experimentally milled flour than from the commercially milled flour.
Further substantiation is given in Figure 2, which shows the starch
and amylodextrin obtained from a baker's patent flour (tube A) in
comparison with that washed from a sample of the middlings from
which the flour was ground (tube B).   There was much less of the
amylodextrin fraction from the latter than from the former.

After decanting the liquid from the centrifuge tubes, the starch
and amylodextrin may be remixed and dried together or they may
be separated and dried individually at room temperature under a fan.

Baking Results with Synthetic Doughs

If the starch, amylodextrin, and wet gluten from a flour are re-
combined in a dough, baking characteristics similar to those of the
original flour are obtained.   Figure 3 shows loaves baked from two
hard-wheat, unbleached, experimentally milled flours as contrasted
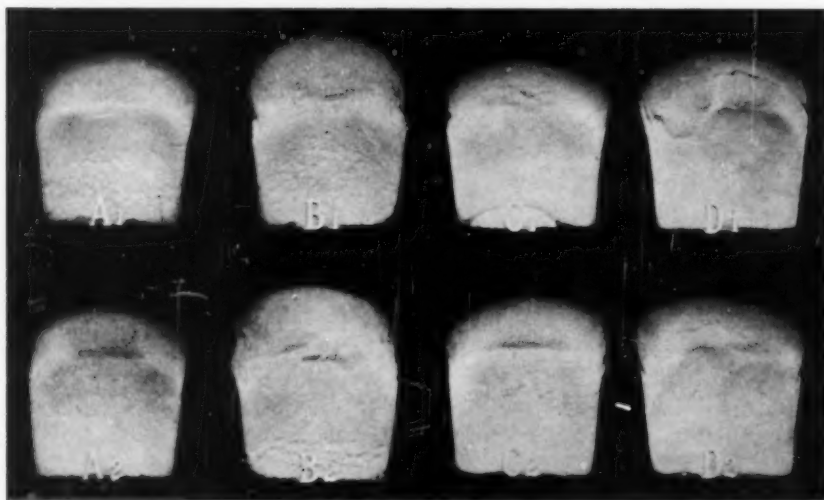
Fig. 3.   Comparison of loaves baked from flour with loaves baked from
recombined gluten, starch, and amylodextrin.

with those baked from the recombined starch, amylodextrin, and wet glutens.   Loaves A_1 and B_1 represent one flour: basic (volume 550 cc.) and plus 1 mg. $KBrO_3$ (volume 605 cc.) respectively.   Loaves A_2 (volume 550 cc.) and B_2 (volume 635 cc.) are the corresponding synthetic loaves.   Loaves C_1 and D_1 were baked from a flour with different characteristics, C_1 being the basic loaf (volume 515 cc.) and D_1 the oxidized loaf (volume 570 cc.). C_2 (volume 530 cc.) and D_2 (volume 560 cc.) are the comparable loaves baked from the starch, amylodextrin, and wet gluten.

These comparative results show that there is a similarity between the "synthetic" loaves and the loaves baked from the original flours and permit the conclusion that the results obtained by this method reliably reflect the properties of the flour constituents as they occur in the original flour.   This would also indicate that those water-soluble constituents removed in washing the gluten and starch are either not essential or that they exert their effect before being washed out.

Baking Procedure

If wet crude gluten is washed and squeezed free from excess water by one operator, it is found to be quite consistent in composition from day to day and even from one flour to another.   As prepared in this laboratory the gluten usually contains 68% to 70% water and about 27% protein.   The starch as dried contains about 10% moisture.   In the following studies on the properties of the starches, amylodextrins, and glutens an arbitrary formula was used to provide dough which approximated that from an 11.5% gluten flour.   The formula is as follows: 42 g. of wet crude gluten containing 29 cc. of water and 11.3 g. of protein is combined with 77 g. of starch (dry weight) or the same quantity of starch plus amylodextrin.   The absorption of this dough when starch plus amylodextrin is used is about 60% to 65% on a 15% moisture basis, practically the same as that of a corresponding flour.   Seven grams of sugar in these synthetic doughs has been found amply sufficient for a three-hour fermentation.

The technique of mixing the wet gluten with the starch and other ingredients is as follows: The ingredients including about two-thirds of the starch are placed in the Hobart-Swanson mixer.   The gluten is soon disintegrated and the mixture becomes exceedingly slack; then the remaining starch is added.   It is necessary to loosen the starch that becomes caked on the bottom of the mixer bowl and to strip the dough from the mixer pins whenever it begins to "ride."   The mixing is continued until the bowl cleans and the dough becomes smooth. The total time spent in the mixing operation is usually four or five minutes.

If dry gluten is to be used, it must be dried at room temperature as rapidly as possible (Aitken and Geddes, 1938). Hanging the wet gluten in a thin sheet over a cord stretched between supports offers a maximum of drying surface to the breeze from a fan (DuBois, Hutton, and Moxon, 1938). The dried gluten is ground in a burr or coffee-type mill.

Since coarsely ground dry gluten hydrates slowly and consequently must soak sometime before the final mix, a sponge method or a soaker method is used. In the sponge-dough method, the ground gluten is mixed with the starch; then the other ingredients are added and mixed to a paste with a spatula; this is given 1½ hours' fermentation to allow for the hydration of the gluten and then remixed in the Swanson mixer to a smooth dough. It is then given another hour and a half fermentation with a punch at one hour.

In the soaker procedure the gluten alone is mixed with the water and allowed to soak for two hours. By this time the gluten has assumed the character of ordinary wet gluten and consequently the mixing procedure is the same as that for wet gluten and starch.

Water Absorption

It was shown in Figure 3 that if the gluten, starch, and amylo-dextrin are recombined in a dough, the baking characteristics are similar to those of the original flour. If the amylodextrin fraction is left out of the dough, the characteristics are considerably changed. The absorption drops about 10%. This suggests that the available starch, the precursor of the amylodextrin fraction of the starch, is a factor influencing the absorption of flour. Alsberg (1935) postulated that this might be the case. (See also Pulkki, 1938.) As is well known, differences in protein content are also factors affecting the absorption. As was shown in Figure 1, soft-wheat flours yield considerably less of the amylodextrin fraction than the hard-wheat flours, and the durum flours yield much more; this corresponds with the well-known differences in the absorptions of these flours. Durum starch (minus the amylodextrin) gives an absorption about 7% above that obtained when the other starches are used. But with this exception, the differences found in the absorption of the glutens or of the undamaged starches (excluding the amylodextrin fraction) of the different flours which we have used have been insignificant, accounting for less than 1% of variations between flours. Shollenberger and Coleman (1926) working with wheat middlings ground to varying degrees of fineness showed that water absorption had a very marked tendency to increase with each increase in degree of fineness of grinding and that this tendency was very much more pronounced with the

hard than with the soft wheats. This is further evidence that the amount of damage to the starch in milling is dependent on the hardness of the wheat. It is noteworthy (Fig. 4) in this connection that purified middlings (from a hard-wheat mix from a commercial mill) that were fine enough to pass a 50GG bolting cloth and coarse enough to be retained on a 70GG cloth were baked (with $KBrO_3$) into an excellent loaf of bread but the absorption was low—in this case only 55%—while the absorption of the flour milled from a sample of these middlings had an absorption of 60%. A comparison of the starches and amylo-dextrins from these middlings and from the flour was shown in Figure 2. This confirms the conclusion that the amylodextrin fraction of a flour is greatly affected by the severity and fineness of grinding and that the amylodextrin fraction in its turn affects the absorption.

Figure 4 shows the comparative characteristics of the loaves baked from the flour and from the middlings. Loaves A and B represent the flour, basic and with 1 mg. $KBrO_3$ respectively. Loaves C and D are from middlings correspondingly treated.
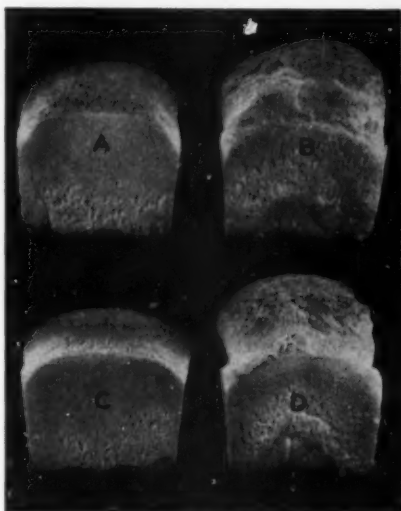
Fig. 4.   Comparison of loaves baked from flour and from middlings.
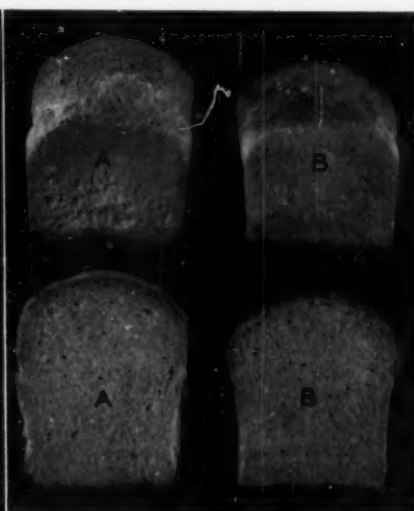
Fig. 5.   Effect of the amylodextrin on loaf characteristics.

Handling Characteristics of Synthetic Doughs

The handling properties or "feel" of a dough made from starch, amylodextrin, and gluten are similar to those of a dough made from flour. But if the amylodextrin fraction is left out, the handling properties are completely changed. The amylodextrin-free doughs are not sticky even when they are exceedingly slack. Stickiness in doughs seems to be associated with this amylodextrin fraction. Dur-

ing fermentation there is always a surface layer of moisture on the amylodextrin-free dough, as though some syneresis were occurring. The absorption is also quite critical, small differences in the water added making a big difference in slackness.   These amylodextrin-free doughs bake into loaves with greater oven spring and greater volume than the doughs containing the amylodextrin.   The loaves shown in Figure 5 illustrate the characteristic effect of the amylodextrin fraction on loaf characteristics.   Loaf A was baked from gluten plus starch without the amylodextrin fraction while loaf B was baked with starch plus the amylodextrin.   The drastic effect produced by the addition of some samples of amylodextrin is illustrated in Figure 6.   Loaf A
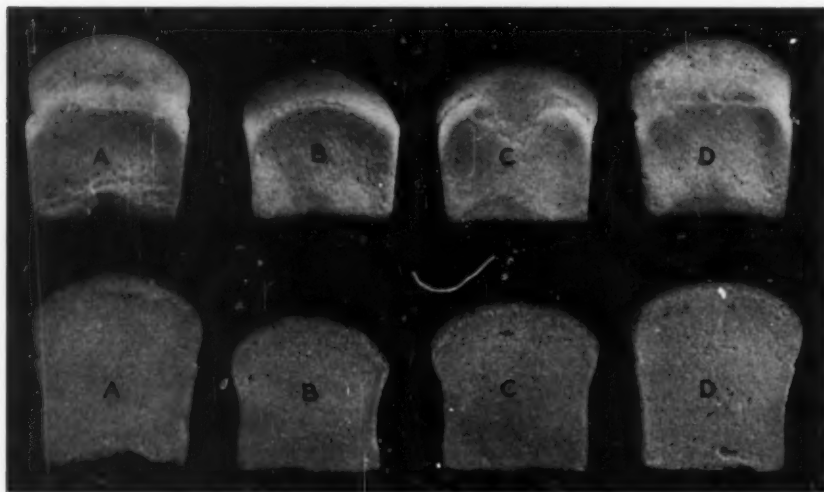
Fig. 6.   Effect of amylodextrin on loaf characteristics.

was baked from gluten and starch without amylodextrin, loaf B contained the amylodextrin, loaves C and D contained the amylodextrin but with the addition of 1 mg. of $KBrO_3$ in C, and the water extract of one gram of malted wheat flour in D.   From the appearance of the loaves one might suspect that the amylodextrin acted as a reducing agent but this does not seem to be the case since oxidation does not eliminate the effect.

The presence of the amylodextrin fraction of starch in synthetic doughs has a very marked tenderizing effect on the crumb of the baked loaf.   The crumb of those loaves baked from gluten and starch without the amylodextrin is decidedly tough and "rubbery" while the crumb of loaves containing the amylodextrin is similar in tenderness to loaves baked from flour.

Effect of Malt

Malt is used in baking not only to increase the gassing power of the flour but also because of its peculiar ability under some conditions to improve the gas-retaining properties of flours.   This improvement has long been attributed to a softening effect on the gluten or, in other words, to its proteolytic action.   It is noteworthy in this regard that some unbleached flours which supposedly, according to the theory of Balls and Hale (1936) and Jørgensen (1935), would require oxidation to inhibit proteolysis are remarkably improved by malt treatment. In fact it is quite difficult to distinguish the improving effect of malt from oxidation on some flours.   Figure 7 shows pictures of loaves of bread baked from an unbleached 85% baker's patent flour with a
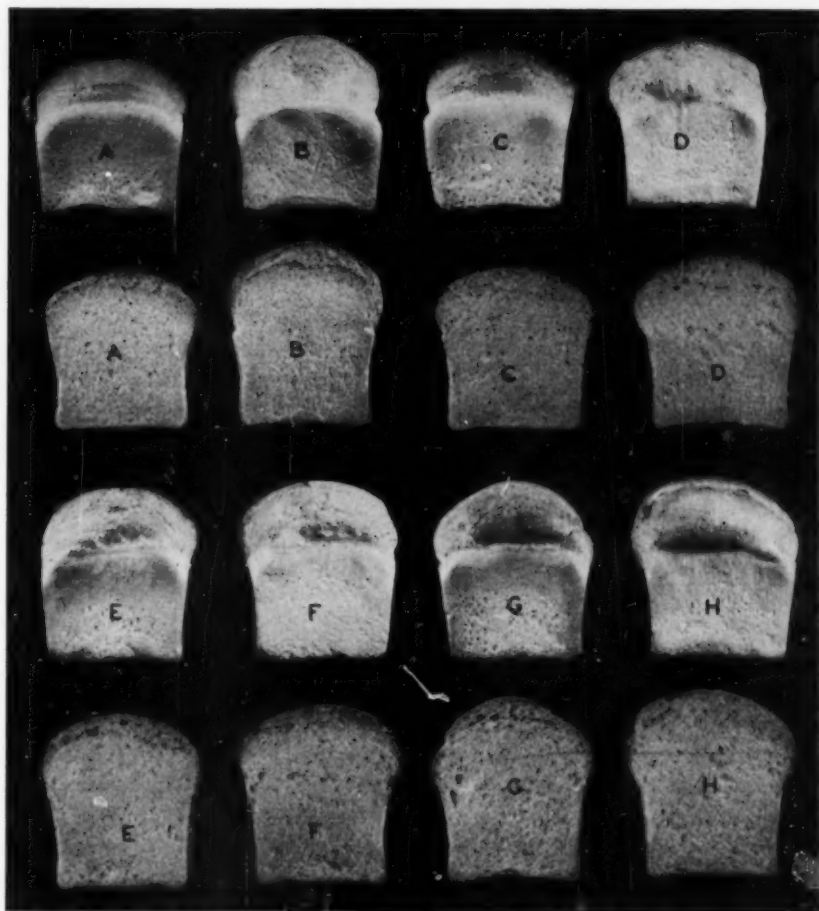
Fig. 7.   Comparison of bromate effect and malt alpha-amylase effect on an unbleached baker's patent flour.

protein content of 12.5% with increasing increments of malt alpha-amylase.

Loaf A (volume 530 cc.) is the basic loaf with no alpha-amylase, loaf B (volume 630 cc.) had 1 mg. of KBrO₃; C (volume 570 cc.) had alpha-amylase equivalent to 0.5% of malt; D (volume 635) had 0.5% malt equivalent of alpha-amylase plus 1 mg. of KBrO₃; E (volume 650) had 2½% malt equivalent of alpha-amylase; F (volume 715) had 2½% malt equivalent alpha-amylase plus 1 mg. KBrO₃; G (volume 675) had 6% malt equivalent of alpha-amylase; and H (volume 750) had 6% equivalent plus 1 mg. KBrO₃.

It is seen that this flour, even though needing and responding to oxidation, was stimulated by malt alpha-amylase. There was an excess of sugar in all of these bakes—5% sucrose added to the flour
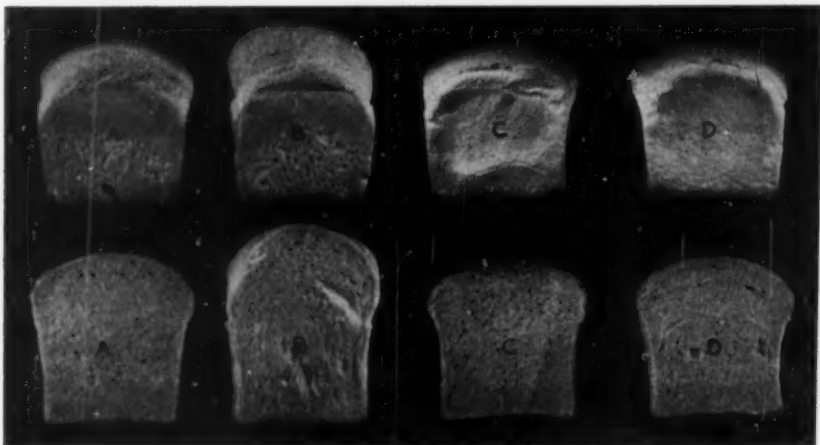
Fig. 8.   Differences in starch response to malt alpha-amylase treatment.

with a maltose value of 190.   The alpha-amylase-treated, unoxidized loaves E and G have an appearance and volume similar to the oxidized loaf (B).   The effect appears to be the result of the action of alpha-amylase on the starch and not the result of proteolysis.

All flours do not respond equally to the addition of malt or malt alpha-amylase.   If the effect is on the starch it would be expected that the starches from these flours would give a corresponding response in synthetic doughs.   That starches respond differently to malt extract is shown in Figure 8.   These loaves, baked from starch-gluten doughs, all contain 42-g. increments of the same wet gluten.   Loaves A and B contain 86 g. each of one sample of starch, without and with the addition of the water extract from 1 g. malted wheat flour.   Loaves C and D were similarly treated but contained a starch which did not respond to malt treatment.   This same type of result is obtained

regardless of whether malt flour, malt extract, or malt alpha-amylase is used. These results indicate that the starch and not the gluten characteristics determine the amount of stimulation by malt alpha-amylase.

Certain flours contain starch which responds more readily than others to malt treatment. The Chiefkan flours which we have investigated are conspicuous in this respect. Figure 9 shows loaves baked from Chiefkan flour (*A*, *B*, *C*, and *D*) and from Chiefkan starch and gluten (*E*, *F*, *G*, and *H*); *A* and *E* are the basic loaves, while *B* and *F* contained malt extract equivalent to 1% of malt. *C* and *D* are the bromated-flour loaves, without and with, respectively, the equivalent of 1% malt. *G* and *H* are the synthetic loaves, correspond-
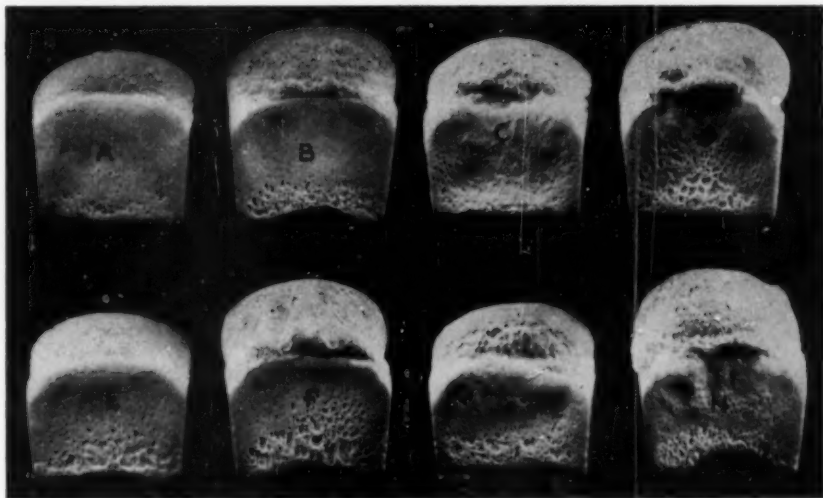
Fig. 9.   Response of Chiefkan flour and Chiefkan starch to malt extract.

ing to *C* and *D*. It will be noticed that this Chiefkan flour was stimulated by malt but did not give a good response to oxidation.

That some of the undesirable characteristics of flours of certain exceedingly hard wheats, such as durum and possibly Chiefkan, may be attributed to the starch and probably to the damage done to the starch in the milling process is shown in Figure 10. These loaves all contain 42-g. increments of the same baker's patent flour gluten. The starch used in loaves *A*, *B*, *C*, and *D* was washed from durum flour while that used in loaves *E*, *F*, *G*, and *H* was washed from durum semolina. Loaves *A*, *B*, *E*, and *F* are the amylodextrin-free loaves; while *C*, *D*, *G*, and *H* contain the amylodextrin. Loaves *B*, *D*, *F*, and *H* were treated with 1% malted wheat flour. The differences between loaf *A*, from durum-flour starch, and loaf *E*, from durum-

semolina starch, would seem to be due to the damage done to the starch in milling the flour from the semolina.   The loaves shown in Figure 4 indicate a similar though less pronounced tendency between the middlings and flour from a commercial hard-wheat mix.   Comparing loaves B and F (Figure 10) it is seen that the malt treatment virtually eliminated the differences.   In comparing loaves D and H with B and F it is seen that though a malt treatment overcomes some of the effect of the amylodextrin, the loaves are still not as good as the malt-treated, amylodextrin-free loaves.

Fig. 10.   Comparison of loaves baked from durum flour starch and durum semolina starch.

In connection with the improving effect of malt on the starches, its effect on the "commercial" wheat starch, which we found had exceedingly poor baking properties, should be noted.   Figure 11 shows loaves baked from doughs using a baker's patent flour gluten in combination with "commercial" wheat starch.   The starches used in this series, in the order in which they occur in the figure, were given a 4-hour preliminary treatment with malt alpha-amylase equivalent to 0%, 1%, 2%, and 4% of malt respectively.   The treated starches were then redried and used for these bakes.   The volumes of the loaves increased from 415 cc. to 690 cc.   That the alpha-amylase in this case must be given considerable time in which to act is shown in Figure 12.   The commercial starch used in loaf A had no preliminary treatment but an alpha-amylase solution equivalent to 4% malt was added to the dough at the mix.

The starch used in loaf *B* (Fig. 12) had the four-hour prelimi-
nary treatment with the same quantity of alpha-amylase. These
results further indicate that the improving action of malt is on
the starch and not on the gluten since the malt alpha-amylase was
acting for the same length of time on the gluten in these two loaves.
Since commercial wheat starch is given a treatment with hypochlorite
in the process of purification it was thought that this might possibly
be the treatment which caused its detrimental properties when it is
used in dough. Accordingly laboratory-prepared starch was sus-
pended in water and chlorine gas added. This chlorine treated starch
when dried had similar properties to the commercial-starch and it
also was improved by malt treatment. No explanation of this
improvement by malt is apparent.
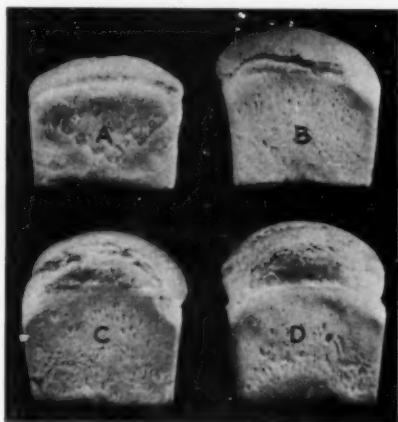
Fig. 11. Loaves baked from a commercial
wheat starch with increasing malt alpha-
amylase treatment.

Fig. 12. Effect of time on response to malt
alpha-amylase.

Summary

Starch and gluten which have been washed from flour may be
recombined to form a dough with baking characteristics similar to
those of original flour doughs. Various combinations of starch and
gluten fractions, and of various treatments, can be suitably studied
by this technique.

The starch from flour may be separated into two fractions by
centrifuging. One of the fractions is relatively pure starch and the
other (smaller fraction) contains the dextrins produced by the action
of the amylases of the flour on the readily available starch; this
fraction is tentatively designated as amylodextrin.

The amylodextrin fraction of the flour is a factor in absorption
and determines to a marked extent the handling characteristics of

flour doughs.   It is closely associated with stickiness of doughs and with tenderness of crumb in the baked loaf.

The improving effect of malt on many flour doughs is due not to its proteolytic action but to the action of alpha-amylase on the starch.

Certain undesirable baking characteristics of some exceedingly hard wheat starches are due to damage to the starch in milling.

Some commercial wheat starches seemingly owe their poor baking properties to hypochlorite treatment.   The detrimental effect of the hypochlorite may be overcome by treatment with large quantities of malt, the effective agent apparently being the alpha-amylase component of malt.

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A COMPARISON OF METHODS FOR THE DETERMINATION OF PROTEOLYTIC ACTIVITY [1]

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Investigations of the relative utility of various methods for determining the proteolytic activity of cereal products have been reported from time to time by Cairns and Bailey (1928), Brownlee and Bailey (1930), Herd (1931), Tissue and Bailey (1931), and Laufer (1937). Of the various procedures studied, the copper-precipitation method of

Ritthausen (1872) as modified by Blish (1918), and later by Olsen and Bailey (1925), and the Sørenson formol titration appear to be the most suitable.

Recently two new methods have been proposed, the gelation-rate procedure of Landis and Frey (1938) and the viscometric method of Koch, Nelson, and Ehrnst (1939). The present study was designed to compare the results obtained with these procedures with those given by the copper-precipitation technique and the formol titration as modified by Samuel (1934). The experiments were conducted in two series. Initially, the Ritthausen method and the modified Sørenson procedure were compared.

Since it was found that both methods gave essentially the same results, the Sørenson technique alone was used in the second series in comparison with the gelation-rate and viscometric methods. To afford information as to the effect of variation in substrate, in the second series the formol titration was used with both flour and gelatin.

Experimental

For the comparison of the Ritthausen copper-precipitation and formol titration methods six samples of southwestern patent flours from the 1937 crop year were tested. In the second comparison fifteen samples covering a reasonably wide range of cereal products were studied by the four methods mentioned above. A description of the second series of samples is included with the data in Table II.

The Ritthausen method was used essentially as described by Blish (1918) and Olsen and Bailey (1925). Autolytic digestions were carried out at 40°C. for 48 hours.

For comparison with the copper-precipitation method, the same samples were also digested for 48 hours at 40° and the increase in amino nitrogen determined by means of the Sørenson formol titration as modified by Samuel (1934).

In preliminary experiments with the rate-of-gelation procedure as described by Landis and Frey (1938), difficulty was encountered in preparing replicate gelatin dispersions of reasonably uniform gelation characteristics. This trouble was overcome by resorting to a technique suggested by the work of Davis, Oakes, and Browne (1921). The desired amount of gelatin was placed in a tared flask, the proper amount of buffer and water added, and the mixture placed in an ice box at 5°C. for 7 to 8 hours. At the end of this time the gelatin was dispersed by heating the mixture to exactly 75°C. in a water bath held constant at 80°C. After cooling to approximately 40°C., sufficient water was added to bring the total to the desired weight and the dispersion then placed in the 30° constant-temperature bath. In other

respects the procedure as used was precisely that described by Landis and Frey (1938).

The viscometric procedure reported by Koch, Nelson and Ehrnst (1939) was also somewhat modified.   It was found that a 7.5% concentration of gelatin gave a more satisfactory dispersion with the particular gelatin employed.   In the calculation of results the unit of proteolytic activity was taken as 100 times the reciprocal of the time necessary to reach a 20% drop in viscosity.   This form of calculation seems preferable since it gives rise to values which are directly proportional to the concentration of the material used and hence presumably to the enzyme concentration.   It was subsequently found that this

TABLE I

COMPARISON OF RITTHAUSEN AND FORMOL TITRATION METHODS

Sample No.	Averages of triplicate determinations	
	Ritthausen method, N not precipitated by $Cu(OH)_2$	Formol titration—increase in amino N
	Mg. per 10 g.	Mg. per 10 g.
	A	B
1	3.82	0.25
2	4.80	0.49
3	4.36	0.42
4	6.46	0.60
5	8.02	0.74
6	3.00	0.35

rAB = +.990   5% pt. = 0.754   1% pt. = 0.874

TABLE II

COMPARISON OF PROTEOLYTIC ACTIVITY VALUES

Sample		Landis and Frey		Koch, Nelson, and Ehrnst		Formol titration—increase in amino N			
No.	Description					Gelatin		Flour	
		Milliunits per g.		Units per g.		Mg. per 10 g.		Mg. per 10 g.	
1	Patent, A mix	0.3	0.3	1.2	1.1	1.2	1.3	0.4	0.4
2	1st clear, A mix	0.8	1.0	2.0	1.8	2.0	2.0	0.6	0.9
3	2nd clear, A mix	3.8	3.5	2.3	2.1	3.0	3.4	1.3	1.3
4	Patent, B mix	0.5	0.6	1.9	1.9	1.3	1.3	0.4	0.6
5	1st clear, B mix	1.3	1.2	3.4	3.2	2.7	2.3	0.8	0.9
6	2nd clear, B mix	5.0	4.7	4.3	4.0	3.0	3.0	1.4	1.3
7	Bran, A mix	3.9	3.5	3.6	4.0	3.0	4.2	5.0	5.0
8	Red Dog, A mix	7.0	9.2	7.1	6.5	6.6	5.3	2.3	2.2
9	Malt flour 1	2.1	2.0	1.8	1.9	2.0	2.0	1.5	1.0
10	Ground whole malt	3.9	3.9	3.0	2.9	5.4	5.1	3.4	2.9
11	Malt flour 2	6.5	5.9	4.2	3.8	3.7	3.6	2.9	2.5
12	Ground acrospires and roots from malt	10.4	10.2	6.3	5.9	32.8	36.8	16.8	12.9
13	Wheat germ 1	14.3	15.6	5.6	5.3	3.1	3.6	4.4	3.8
14	Wheat germ 2	10.8	12.1	5.6	4.8	4.4	4.3	3.6	4.1
15	Papain	3.3×10^4	3.6×10^4	2.5×10^3	2.3×10^3	2.8×10^3	2.8×10^3	8.8×10^3	9.0×10^3

form of expression gave results consistently in better agreement with those of the other methods.

The formol titration procedure used with the second series of samples in comparison with the rate-of-gelation and viscosity methods was essentially that described by Samuel (1934). In one instance a 3% gelatin dispersion in $M/20$ acetate buffer of pH 5.0 was used as substrate. In the second case, the substrate was a 10% suspension of a southwestern patent flour in the same buffer. To both substrates were added aqueous extracts, usually 20%, of the material to be tested. Duplicate digestions were carried out at 40°C. for 48 hours, together with appropriate control determinations in each case for both the substrate alone and for the extract alone.

The results obtained are shown in Tables I and II and an analysis of the data obtained for the second series of samples is given in Tables III and IV.

TABLE III

CORRELATION COEFFICIENTS FROM DATA OF TABLE II

	Landis and Frey	Koch, Nelson, and Ehrnst	Formol gelatin
Koch, Nelson, and Ehrnst	+.855	—	—
Formol gelatin	+.413	+.512	—
Formol flour	+.554	+.590	+.947
	5% pt. = 0.532		

TABLE IV

SUMMARY AND ANALYSIS OF DATA FROM TABLE II

	Landis and Frey	Koch, Nelson, and Ehrnst	Formol titration—increase in amino N	
			Gelatin	Flour
	Milliunits per g.	Units per g.	Mg. per 10 g.	
Mean	5.58	3.92	5.88	3.28
Range	0.3–15.6	1.1–7.1	1.2–36.8	0.4–16.8
Standard error of single de-determination	0.16	0.16	0.21	0.27
Coefficient of variation, %	2.87	4.08	3.57	8.23
	ANALYSIS OF VARIANCE			
Variance between duplicates	0.02577	0.02638	0.04400	0.07462
Variance between samples	38.241	5.7949	136.73	25.989
F	1484.0	219.67	3107.5	348.28
5% pt.	2.55	2.55	2.55	2.55

Discussion

The data given in Table I [2] show that the Ritthausen method and the formol titration procedure as modified by Samuel give essentially

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[2] I am indebted to Mr. H. F. Vaupel for making these determinations and for his assistance in preliminary studies with the Landis and Frey method.

similar results. This is in agreement with the conclusions previously reached by Tissue and Bailey (1931) and by Blish (1918).

The analysis shown in Tables III and IV was computed from results with only the first 14 samples for all methods. The last sample, which was one of papain, was so far removed from the range of activity of the other materials tested as to influence unduly any analysis of data in which it was included.

The correlation coefficients indicate that the gelation-rate and viscometric methods give results which are in good agreement between themselves. The same is true of the formol titration procedures using gelatin and a flour suspension as substrates. In contrast the correlation is relatively poor between either the gelation or viscometric procedures and either type of formol titration. This suggests that the physical methods (gelation-rate and viscometric) are measuring a different type of activity from that tested by either the formol titration or copper-precipitation procedures. It may reasonably be assumed that the physical methods measure proteinase activity—that is, degradative or disaggregative action on the whole protein—whereas the other methods are based on an increase in products of low molecular weight, which would be produced to a greater extent by the action of dipeptidases and/or polypeptidases. It has always been assumed that proteinase activity is of the more importance in relation to dough fermentation problems, and in such connection the gelation-rate or the viscometric method would be the more suitable.

In referring again to the original data, it seemed possible that much of the difference in results between these two classes of methods might be ascribed to the values given by sample No. 12. Correlation coefficients were again calculated omitting this sample and all were found to lie within the range $+ .82 \pm .05$ except that between the gelation-rate and formol-gelatin procedures which was $+ .58$. Clearly, the distribution of the protease systems in samples other than No. 12 is essentially the same. It should not be inferred, however, that these types of methods may be used interchangeably, since a system similar to that of sample No. 12 may be encountered in other materials.

The relative precision of the several procedures may be seen from the values given in Table IV for the standard error of a single determination. These values are not directly comparable since the units by which activity is expressed in the several methods are not the same. In order to facilitate comparison the coefficient of variation—the standard error as percent of the mean for all samples—is also given. Another form of expression of the experimental error is the variance between duplicates shown under the analysis of variance.

The relative ability of a method to differentiate between samples is governed by both the experimental error and the variability between means of samples; the larger the variance between sample means and the smaller the experimental error the greater will be the distinction between samples.　A measure of this differentiation is given by the *F* values, which are an expression of the ratio of the variance between samples to the variance between duplicates.　While these values are not directly comparable they clearly indicate that as between the viscometric and rate-of-gelation procedures the latter is to be preferred since it gives a much greater distinction between samples.　By the same reasoning the use of gelatin as a substrate in the formol titration method is to be preferred to flour since the experimental error is lower and the differentiation between samples higher.

Of the procedures studied, the formol titration method is least time consuming, while there is little to choose in this respect between the gelation-rate, viscometric, and copper-precipitation methods. The gelation-rate procedure has the serious disadvantage of requiring a considerable amount of highly specialized and expensive apparatus, which is not the case with the other methods.

Summary

The rate-of-gelation and viscometric methods of determining proteolytic activity recently proposed by Landis and Frey (1938) and by Koch, Nelson, and Ehrnst (1939) have been investigated in comparison with the copper-precipitation and formol titration procedures, using in the last case both gelatin and a flour suspension as substrates.　This comparison has been carried out with a series of samples comprising a reasonably wide variety of cereal products.

With the limited number of samples tested, the gelation-rate and viscometric methods gave results substantially different from those obtained with the other procedures.　It may be presumed that the first two methods measure proteinase activity, while in the other types of procedure dipeptidase and/or polypeptidase action have the most effect on the results obtained.

In these experiments, the gelation-rate and viscometric methods had the same experimental error, but the former seems preferable because of its better differentiation between samples.　The use of the gelation-rate procedure is limited by its requirement of relatively elaborate and costly apparatus.

The modified Ritthausen copper-precipitation and formol titration methods used were found to give essentially the same relative results.

In the formol titration procedure the use of gelatin as a substrate seems preferable to that of flour since this technique leads to lower experimental error and better differentiation between samples.

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CHANGES IN FLOUR ON STORAGE WITH SPECIAL REFERENCE TO THE EFFECT OF DIFFERENT TYPES OF BAGS

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Flour storage in different types of containers has been the subject of several researches. Swanson, Willard, and Fitz (1915) found that storage in sealed jars or in cloth sacks made little difference in its behavior as to baking quality during storage. Miege (1933) studied the maturing of wheat and flour in bags, in bulk covered at 21°C., in air day and night, and in hermetically sealed bottles. He concluded that the tenacity and baking value of the milled flour was greatly improved by storage and that the tenacity of the gluten was greatest in the closed samples after six months of storage and also that the amount of moisture was greater in samples left in the open air in bulk.

Kuhl and Kliefoth (1934) found that the keeping quality of a flour stored for six months was better when it was compressed into a solid mass than when stored in the usual form in cloth sacks.

Krtinsky (1937) studied flour storage in jute and paper bags.   The factors considered were moisture, gluten content, and gluten quality over a period of three months.   Krtinsky concluded that at room temperature the changes incident to storage were similar for flour stored in these two types of containers, both of which were found satisfactory.   However, he found a greater rate of moisture loss in jute bags than in paper bags, while gluten content, gluten quality, and increase in absorption were the same during the storage period in the two bags.

Thiessen (1933) found that the absorption of Wyoming hard-wheat flours increased 6% to 10% during 12 months of storage in cotton sacks, and only 0% to 2% during 21 months storage in cans.

Fisher, Halton, and Carter (1937) stored flours in cubical sealed tins and bags and studied the effect of storage over a period of 18 months.   They found that "the bagged and tinned dry (12% moisture) samples showed closely similar changes in chemical composition during 18 months' storage, and the changes were by no means marked. On the whole the tinned dry samples showed smaller changes than the corresponding bagged (and slightly moister) samples."   The fact that the bagged samples were slightly more moist may account for this. The glutens from the bagged and tinned dry samples of English patent showed very little change either in quality or quantity.

Although the intention in the present research was to study the effect of cotton, jute, paper-lined, and grain bags on the storage of flour, certain factors of significance have been found during the course of the tests which have extended the scope of the findings to include observations of the general effect of storage of flour on absorption, ash, protein, flour weight, and baking quality.   In view of this, it is probably advisable to review some of the previous researches on these factors.   The following citations are somewhat confusing, thus indicating the need for further research.

Bailey (1925) has summarized the literature up to 1925 in regard to the changes in flour incidental to aging.   The early researches in regard to the effect of humidity on the weight of flour, summarized by Bailey, point out first that because of the fine state of division and the greater exposure resulting from the method of handling, flour responds more readily to changes in humidity of the storage room than does bulk grain; second, these researches demonstrate the hygroscopicity of flour; and third, they show that the amount of moisture in flour varies with the humidity of the storage room in which it is stored.   Arpin and Pecaud (1923) found that small packages of flour showed greater change in weight than did larger packages when stored in the same atmosphere.

Bailey (1925) mentions that various investigators have shown that natural aging of flour results in an improvement of the color score due

to the "spontaneous oxidation of the carotinoid pigments." Swanson, Willard, and Fitz (1915) found that freshly milled flour reached its maximum color score in 305 days whether stored in heated or unheated rooms and then in some samples fell off slightly up to 366 days. However, Saunders, Nichols, and Cowan (1921) found that wheat stored and baked at various intervals reached a maximum color score in three years and maintained about the same level for ten years.

Sharp (1924) has shown the effect of moisture content and temperature on the keeping qualities of flour as indicated by changes in acidity. His work shows that lower temperatures and lower moisture contents favor longer keeping qualities, while higher temperatures and higher moisture contents show that flour will remain sound for much shorter lengths of time. Also, flour with a moisture content of 14.4% would remain sound only if kept at abnormally low temperatures. However, Reimund (1916), as reported by Bailey, believed that flour could be stored at 18°C. without spoiling if the moisture content did not exceed 15%. Mangels (1924) gives evidence supporting the belief that warm storage of flour is more detrimental than cool storage. The volumes of loaves from flour stored in warm storage showed a greater decrease after three or four months than did the flour from cool storage. Halton and Fisher (1937) have found that flour can be safely stored and exported even into tropical countries if the moisture content is not above 12% and that it is not necessary to go below 12% in order to insure safe storage. Greaves and Hirst (1925) state that highly milled flour from sound wheat can be stored in dry rooms free from odors for at least four years without deteriorating; however, poor-grade flour deteriorates more rapidly.

Many writers have investigated and emphasized the tendency of bacteria, mold, and insects to grow in flour in the higher-moisture brackets at warm temperatures, and of course almost every baker realizes the danger of storing moist flour at warm temperatures.

Several investigators have conducted researches into the effect of storage of flour on baking quality. All of the investigations show an improvement in coloring and strength and general baking qualities on storage. The most extensive work has been reported by Swanson, Willard, and Fitz (1915) and Saunders, Nichols, and Cowan (1921). Swanson, Willard, and Fitz studied the effects of storage on the baking quality of flour stored in sealed jars and in cloth sacks. The baking quality (loaf volume and "gluten quality factor") increased up to about 125 days or more and then diminished up to 366 days. However, the baking tests indicated that the "strength" at the beginning of the test was not so good as after 366 days. Bleached flour was included in the series and showed about the same trend as the unbleached samples.

Saunders, Nichols, and Cowan found that flour showed an increase in loaf volume and baking strength for two to three years. This was then followed by a decrease. Yet at the end of twelve years' storage the data show baking strength superior to that at the start of the experiment. Their data indicate that flour stored under good conditions can be kept for ten years.

The experiments of Saunders, Nichols, and Cowan (1921) show an increase in absorption with time of storage; at the end of about thirteen years the increase in absorption was enormous (about a 24% to 25% increase). Stockham (1917) reported that fresh flour increased in absorption 1.2% after eight months storage.

Greaves (1925) confirms the fact that water-absorption power of flour is increased during storage. He also reports that some flours yielded a loaf of greater volume after storage whereas others registered a smaller volume. He concludes that on the whole bread-making flour is improved in baking quality on storage.

Thiessen (1933) studied the effect of aging on Wyoming hard-wheat flours stored in both cotton sacks and tightly closed cans and concluded that an aging period of from one to three months improved flour and after three months there was little further change for about two years, but after two years deterioration set in and increased rapidly to the four-year period. Throughout the storage period the water-absorption power of the flour increased and was most rapid when the flour was stored in sacks.

Kuhl and Kliefoth (1934) found that flour treated with $KBrO_3$ and electrically bleached does not keep as well as untreated and unbleached flour and that the electrically bleached and treated flour falls off somewhat in baking quality on storage.

Kozmin (1935) stored flour at various temperatures in hermetically sealed jars. After three months, flour stored at 15°C. showed practically no change in the quality of the gluten, while flour stored at 30°C. and 45°C. showed the effect of aging. Kozmin found that aging strengthened the gluten and that this took place much more rapidly at the higher temperatures. The flour was not chemically aged or bleached.

Kent-Jones (1924) reports the changes in flour or aging for five months as follows: (1) the ash showed little or no change; (2) nitrogen scarcely changed; (3) the crude gluten tended to decrease; (4) the "maltose" figure did not change in the higher grades. Baker and Hulton (1908) found that diastatic activity increased during storage of flour (reported by Bailey, 1925). Hartmann (1930) stored unbleached flour for fifteen months and concluded that the gluten nitrogen decreases on storage at a rapid rate, while Barton-Wright

(1938) reports an increase in soluble nitrogen after ten weeks of storage.

Marotta, Di Stefano, and Vercillo (1935) studied the effect of aging on the diastatic value of flour. They found that neither the diastase value nor the amount of reducing sugar changes during aging.

No mention has been made of the extensive work done on the effect of storage on hydrogen-ion concentration, total acidity, or on the fatty components of flour, since these factors were not considered in the analyses reported in this paper.

Experimental

Two different chemically bleached and matured flours were chosen for this study, the flours being considered as representative bakers' flours. One sample was milled from new wheat only, while the percent of new wheat in the other was not known. Both were high-grade patent flours. The kinds of bags used were paper-lined, jute, grain, and cotton. About 30 lbs. of each sample of flour were stored in each of the four different kinds of bags. Two sets of samples were prepared. One set of samples in each kind of bag was used for weighing at regular intervals, while the other was used for analysis and baking tests. The flour, the sample number, and the kind of bag are shown in Table I. The samples of flour in the various bags will be referred to in later

TABLE I

SAMPLES OF FLOUR AS THEY WERE STORED IN DIFFERENT BAGS

Flour	Sample number	Kind of bag
High-grade chemically bleached and matured patent from all new wheat. Aged normal time at mill before receipt on Nov. 17, 1937.	1B 2B 3B 4B	Paper-lined Jute Grain Cotton
High grade chemically bleached and matured patent. Amount of new wheat unknown. Aged normal time before receipt on Sept. 30, 1937.	5B 6B 7B 8B	Grain Jute Paper-lined Cotton

tables by the sample numbers given in Table I. At regular intervals the flour samples were analyzed for moisture, absorption, ash, and protein; and baking tests were made.

The two different flours were sampled on November 17, 1937. The first analyses and baking tests were made on this date. The recordings of weights, temperatures, and humidity of the storage room were started on November 18th. The flour samples were stored in a dry, clean room in the basement which closely approached average bake-shop conditions. The weight of the bags and the temperature and

humidity of the storage room were recorded daily (data are missing for week-ends and a few other days).

In order to have a comparison of the weights on a commercial scale a skid of the flour in cotton bags (15 bags) used for samples 5B, 6B, 7B, and 8B was placed in a storage room of a commercial bakery and the temperature, humidity, and weight recorded weekly.

The tests were started on the flour used for samples 1B, 2B, 3B, and 4B when it had been aged about as much as is usual when the baker receives it; the other sample was about 45 days older.

All absorptions were determined by mixing flour and water in a Fleischman mixer.   One hundred grams of flour were used and water was run in from a burette during mixing until a dough of a standard consistency was reached.   This standard consistency was determined by the feel of an experienced operator.   The same operator determined the absorptions in all cases.   From experiments the absorptions are correct at least to $\pm$ 0.5 percent.

The methods used for determining moisture,[1] ash, and protein ($N \times 5.7$) were those of the Association of Official Agricultural Chemists. All volumes were determined by the method described by Cathcart and Cole (1938).

Both laboratory and commercial baking tests were performed. The laboratory test was made in a tall-form pan without the aid of enriching ingredients.   It was made in two parts, the second part providing 45 minutes more fermentation time than the first part. This gave an indication of fermentation tolerance and general baking characteristics.   However, in order to obtain a truer picture of how the flour would behave in a bake shop a commercial loaf was baked.   This loaf contained enriching ingredients, yeast food, and was a regular one-pound, round-top loaf of bread.   The straight-dough method of test baking was used throughout.   Data from the two parts of the laboratory loaves were scored under the headings of fermentation tolerance, oven spring, bread quality, aroma and taste, and color of crumb. Each factor was rated as shown in Table II.   Each part of the laboratory baking test was measured for volume and photographs were made.

The commercial loaves were scored for volume, color of crust, symmetry of form, evenness of bake, character of crust, break and shred, grain, color of crumb, aroma, taste, and texture, numerical figures being given in each case.

Results

The data for moisture, absorption, and the baking tests for samples 1B, 2B, 3B, 4B, 5B, 6B, 7B, and 8B are recorded in Table II.   The

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[1] Air-oven method.

TABLE II

DATA ON FLOUR SAMPLES STORED IN VARIOUS BAGS, GIVEN ACCORDING TO THE KIND OF BAG

VG = Very Good, G = Good, FG = Fairly Good, F = Fair, P = Poor, CW = Creamy White, W = White, GW = Gray White, DG = Dark Gray, and GR = Gray.

Sample No. and kind of bag	Date tested	Moisture as received, %	Absorption on 15% moisture basis, %	Volume, cu. in./oz. 1st part	Volume, cu. in./oz. 2nd part	Laboratory baking-test data Tolerance	Oven spring	Bread quality	Aroma and taste	Color of crumb	Commercial baking-test data Vol., cu. in./oz.	Grain, 10	Color of crumb, 10	Aroma, 15	Taste, 20	Texture, 15	Total score, 100
1B, Paper lined	Nov. 17, 1937	11.4	57.3	9.7	9.5	VG	VG	VG	VG	GW	9.8	9.0	9.5	14.0	19	14.0	93.5
	Dec. 1, 1937	11.4	57.8	9.6	10.1	VG	VG	VG	VG	CW	10.7	9.0	9.0	14.0	19	14.0	93.0
	Dec. 15, 1937	11.2	57.9	9.5	9.7	VG	VG	G	VG	CW	9.2	8.5	9.0	14.0	19	13.0	91.0
	Jan. 5, 1938	11.0	58.5	9.1	8.6	VG	VG	G	G	GW	8.3	8.0	8.0	13.5	19	14.0	91.0
	Jan. 26, 1938	10.4	58.0	9.4	8.4	VG	VG	VG	VG	CW	10.0	9.0	9.0	14.0	19	14.0	93.5
	Feb. 16, 1938	10.1	57.4	9.7	9.5	VG	VG	VG	VG	CW	10.2	9.0	9.0	14.0	19	14.0	93.5
	Mar. 9, 1938	9.8	57.3	9.0	8.4	G	VG	VG	VG	GW	10.0	9.0	9.0	14.0	19	14.0	93.0
	April 13, 1938	10.0	58.2	9.1	9.4	G	G	G	VG	GW	10.0	9.0	8.5	14.0	19	14.0	92.5
	May 6, 1938	9.9	58.1	8.8	8.2	G	G	F	FG	GR	9.4	8.5	8.0	13.5	19	13.5	90.0
	June 2, 1938	10.8	59.1	8.8	8.5	G	G	FG	P	GR	9.4	8.0	8.0	12.0	15	13.5	83.5
2B, Jute	Nov. 17, 1937	11.7	57.9	9.3	9.4	VG	VG	VG	VG	GW	9.2	9.0	9.5	14.0	19	14.0	93.5
	Dec. 1, 1937	11.3	57.6	9.6	9.4	VG	VG	VG	VG	CW	10.8	9.0	9.0	14.0	19	14.0	93.0
	Dec. 15, 1937	11.4	58.3	9.5	9.5	VG	VG	G	VG	GW	9.4	8.5	9.0	14.0	19	13.0	91.0
	Jan. 5, 1938	10.9	58.4	9.2	8.3	VG	VG	G	G	GW	8.4	8.0	8.5	13.5	19	14.0	91.0
	Jan. 26, 1938	10.1	57.4	8.6	8.3	VG	VG	VG	VG	CW	9.7	9.0	9.0	14.0	19	14.0	93.5
	Feb. 16, 1938	9.9	57.1	9.4	9.7	VG	VG	VG	VG	CW	10.4	9.0	9.0	14.0	19	14.0	93.5
	Mar. 9, 1938	9.5	56.9	8.6	9.2	G.	G	VG	VG	GW	9.5	9.0	9.0	14.0	19	14.0	93.0
	April 13, 1938	10.2	58.5	9.3	9.3	G	G	G	VG	GW	9.8	9.0	8.5	14.0	19	14.0	92.5
	May 6, 1938	10.1	58.4	7.8	7.5	F	P	P	F	DG	9.5	8.5	8.0	13.5	19	13.0	89.5
	June 2, 1938	11.1	59.7	8.4	8.6	FG	FG	F	P	GR	9.6	7.5	8.0	12.0	15	13.0	82.5

TABLE II—Continued

Sample No. and kind of bag	Date tested	Moisture as received, %	Absorption on 15% moisture basis, %	Volume, cu. in./oz.		Laboratory baking-test data					Commercial baking-test data						
				1st part	2nd part	Tolerance	Oven spring	Bread quality	Aroma and taste	Color of crumb	Vol., cu. in./oz.	Grain, 10	Color of crumb, 10	Aroma, 15	Taste, 20	Texture, 15	Total score, 100
3B, Grain	Nov. 17, 1937	11.4	57.3	9.6	9.1	VG	VG	VG	VG	GW	10.0	9.0	9.5	14.0	19	14.0	93.5
	Dec. 1, 1937	11.4	57.8	9.7	9.3	VG	VG	VG	VG	CW	10.4	9.0	9.0	14.0	19	14.0	93.0
	Dec. 15, 1937	11.2	57.9	9.5	9.5	VG	VG	G	VG	CW	10.2	8.5	9.0	14.0	19	13.5	91.5
	Jan. 5, 1938	10.9	58.4	8.9	8.8	VG	VG	G	G	GW	8.4	8.5	8.5	13.5	19	14.0	93.0
	Jan. 26, 1938	10.3	57.8	9.1	8.6	VG	VG	VG	VG	CW	9.8	9.5	9.0	14.0	19	14.0	93.5
	Feb. 16, 1938	9.9	57.1	9.4	9.5	VG	VG	VG	VG	CW	10.4	9.0	9.0	14.0	19	14.0	93.5
	Mar. 9, 1938	9.9	57.5	9.6	8.6	G	G	VG	VG	GW	9.9	9.0	9.0	14.0	19	14.0	93.0
	April 13, 1938	10.0	58.2	9.4	9.5	G	F	G	VG	GW	9.9	9.0	8.5	14.0	19	14.0	92.5
	May 6, 1938	10.2	58.5	8.7	9.1	G	G	FG	G	GW	9.3	8.5	8.5	13.5	19	13.5	90.0
	June 2, 1938	11.1	59.7	8.6	9.0	G	G	FG	F	GW	9.3	7.5	8.0	12.0	15	13.5	83.0
4B, Cotton	Nov. 17, 1937	12.1	58.6	9.5	9.4	VG	VG	VG	VG	GW	10.7	9.0	9.5	14.0	19	14.0	93.5
	Dec. 1, 1937	11.9	58.7	9.5	9.3	VG	VG	VG	VG	CW	10.6	9.0	9.0	14.0	19	14.0	93.0
	Dec. 15, 1937	11.7	58.8	9.6	9.5	VG	VG	G	VG	CW	10.3	9.0	9.0	14.0	19	14.0	93.0
	Jan. 5, 1938	10.9	58.4	8.9	8.5	VG	VG	G	G	GW	8.4	8.5	8.5	13.5	19	14.0	91.5
	Jan. 26, 1938	10.5	58.1	9.0	9.0	VG	VG	VG	VG	CW	10.0	9.5	9.0	14.0	19	14.0	94.0
	Feb. 16, 1938	10.0	57.2	9.6	9.4	VG	VG	VG	VG	CW	10.3	9.0	9.0	14.0	19	14.0	93.5
	Mar. 9, 1938	9.7	57.2	9.5	8.9	G	G	VG	VG	GW	10.0	9.0	9.0	14.0	19	14.0	93.0
	April 13, 1938	10.2	58.5	9.1	9.1	G	G	G	VG	GW	9.5	9.0	8.5	14.0	19	14.0	92.5
	May 6, 1938	10.3	58.7	8.5	8.9	FG	FG	FG	G	GW	9.0	8.5	8.5	13.5	19	14.0	90.5
	June 2, 1938	11.0	59.5	8.5	8.8	FG	FG	FG	F	GW	9.0	7.5	8.0	12.0	15	13.5	83.0

TABLE II—Continued

Sample No. and kind of bag	Date tested	Moisture as received, %	Absorption on 15% moisture basis, %	Laboratory baking-test data								Commercial baking-test data					
				Volume, cu. in./oz.		Tolerance	Oven spring	Bread quality	Aroma and taste	Color of crumb	Vol., cu. in./oz.	Grain, 10	Color of crumb, 10	Aroma, 15	Taste, 20	Texture, 15	Total score, 100
				1st part	2nd part												
5B, Grain	Nov. 17, 1937	11.8	57.1	9.3	9.2	VG	VG	VG	VG	CW	10.1	9.5	9.5	14.0	19	14.0	94.0
	Dec. 1, 1937	11.8	58.0	9.2	9.3	VG	VG	VG	VG	CW	10.9	9.0	9.5	14.0	19	14.0	93.0
	Dec. 15, 1937	11.6	58.2	10.0	9.7	VG	VG	VG	VG	CW	10.3	9.5	9.5	14.0	19	14.0	94.5
	Jan. 5, 1938	11.1	58.2	9.5	8.9	VG	VG	VG	VG	CW	8.4	9.0	9.0	14.0	19	14.5	93.5
	Jan. 26, 1938	10.4	57.5	9.2	9.3	VG	VG	VG	VG	CW	10.1	9.5	9.0	14.0	19	14.0	94.0
	Feb. 16, 1938	10.1	57.0	9.7	9.3	VG	VG	VG	VG	W	10.6	9.0	9.0	14.0	19	14.0	93.5
	Mar. 9, 1938	9.8	56.8	9.5	9.3	VG	VG	VG	VG	W	9.9	9.0	9.5	14.0	19	14.0	94.0
	April 13, 1938	10.4	58.4	9.5	9.3	VG	VG	VG	VG	CW	9.8	9.0	9.0	14.0	19	14.0	93.5
	May 6, 1938	10.3	58.2	8.7	8.8	VG	G	G	G	W	10.1	9.0	9.0	14.0	19	14.0	93.5
	June 2, 1938	11.0	59.0	9.5	8.5	G	G	FG	F	W	9.1	8.5	8.5	12.0	15	14.0	85.0
6B, Jute	Nov. 17, 1937	12.3	58.0	10.0	9.4	VG	VG	VG	VG	CW	9.4	9.5	9.5	14.0	19	14.0	94.0
	Dec. 1, 1937	12.0	58.4	9.7	9.4	VG	VG	VG	VG	CW	10.6	9.0	9.5	14.0	19	14.0	93.5
	Dec. 15, 1937	11.8	58.5	10.2	9.5	VG	VG	VG	VG	CW	9.9	9.0	9.5	14.0	19	14.0	94.0
	Jan. 5, 1938	11.2	58.4	9.6	9.0	VG	VG	VG	VG	CW	8.6	9.5	9.0	14.0	19	14.5	94.0
	Jan. 26, 1938	10.8	58.2	8.8	9.8	VG	VG	VG	VG	CW	10.0	9.0	9.0	14.0	19	14.0	93.5
	Feb. 16, 1938	10.2	57.1	9.8	9.4	VG	VG	VG	VG	W	10.4	9.0	9.5	14.0	19	14.0	93.5
	Mar. 9, 1938	10.1	57.4	9.3	9.6	VG	VG	VG	VG	W	9.0	9.0	9.5	14.0	19	14.0	94.0
	April 13, 1938	10.4	58.4	9.6	9.4	VG	VG	VG	VG	CW	9.8	9.0	9.0	14.0	19	14.0	93.5
	May 6, 1938	10.1	57.9	8.9	9.1	VG	VG	VG	G	W	10.2	9.5	9.0	14.0	19	14.0	94.0
	June 2, 1938	10.9	58.8	9.7	8.4	G	G	FG	F	W	9.4	8.0	8.5	12.0	15	14.0	84.5

TABLE II—*Continued*

Sample No. and kind of bag	Date tested	Moisture as received, %	Absorption on 15% moisture basis, %	Volume, cu. in./oz.		Laboratory baking-test data					Commercial baking-test data						
				1st part	2nd part	Tolerance	Oven spring	Bread quality	Aroma and taste	Color of crumb	Vol., cu. in./oz.	Grain, 10	Color of crumb, 10	Aroma, 15	Taste, 20	Texture, 15	Total score, 100
7B, Paper lined	Nov. 17, 1937	12.1	57.6	9.8	9.8	VG	VG	VG	VG	CW	9.9	9.5	9.5	14.0	19	14.0	94.0
	Dec. 1, 1937	12.0	58.4	9.7	9.5	VG	VG	VG	VG	CW	10.5	9.0	9.5	14.0	19	14.0	93.5
	Dec. 15, 1937	11.8	58.5	10.6	9.5	VG	VG	VG	VG	CW	10.3	9.0	9.5	14.0	19	14.0	94.0
	Jan. 5, 1938	11.2	58.4	9.4	9.0	VG	VG	VG	VG	CW	8.4	9.0	9.0	14.0	19	14.5	93.5
	Jan. 26, 1938	10.4	57.5	9.2	9.5	VG	VG	VG	VG	CW	10.9	9.0	9.0	14.0	19	14.0	93.0
	Feb. 16, 1938	10.4	57.5	9.4	9.7	VG	VG	VG	VG	W	10.3	9.0	9.5	14.0	19	14.0	93.5
	Mar. 9, 1938	10.2	57.6	9.5	9.3	VG	VG	VG	VG	W	10.0	9.0	9.5	14.0	19	14.0	94.0
	April 13, 1938	10.4	58.4	9.5	9.2	VG	VG	VG	VG	CW	9.8	9.0	9.0	14.0	19	14.0	93.5
	May 6, 1938	10.1	57.9	8.9	8.6	VG	VG	VG	G	CW	9.3	9.5	9.0	14.0	19	14.0	94.0
	June 2, 1938	10.9	58.8	9.5	8.2	G	G	FG	F	CW	9.7	8.5	8.5	12.0	15	14.0	84.5
8B, Cotton	Nov. 17, 1937	11.6	56.7	9.7	9.6	VG	VG	VG	VG	CW	10.2	9.5	9.5	14.0	19	14.0	94.0
	Dec. 1, 1937	11.7	57.9	9.9	9.7	VG	VG	VG	VG	CW	10.5	9.0	9.5	14.0	19	14.0	93.5
	Dec. 15, 1937	11.7	58.4	10.8	9.3	VG	VG	VG	VG	CW	10.1	9.5	9.5	14.0	19	14.0	94.5
	Jan. 5, 1938	11.2	58.4	9.5	9.1	VG	VG	VG	VG	CW	8.4	9.0	9.0	14.0	19	14.5	93.5
	Jan. 26, 1938	10.4	57.5	9.1	9.8	VG	VG	VG	VG	CW	10.8	9.0	9.0	14.0	19	14.0	93.0
	Feb. 16, 1938	10.6	57.8	9.5	9.5	VG	VG	VG	VG	W	10.3	9.0	9.5	14.0	19	14.0	93.5
	Mar. 9, 1938	10.1	57.4	9.7	8.6	VG	VG	VG	VG	W	11.0	9.0	9.5	14.0	19	14.0	94.0
	April 13, 1938	10.4	58.4	9.8	9.1	VG	VG	VG	VG	CW	10.5	9.0	9.0	14.0	19	14.0	93.5
	May 6, 1938	10.1	57.9	9.3	9.1	VG	VG	VG	G	CW	10.0	9.5	9.0	14.0	19	14.0	94.0
	June 2, 1938	11.0	59.0	9.3	8.8	G	G	FG	F	CW	9.0	8.5	8.5	12.0	15	14.0	84.0

data are recorded according to the kind of bag used for storage.   In order to conserve space all of the factors scored on the commercial loaf are not given; only those which are considered to be the most important are presented.

The data on the weights of the various bags of the samples and the humidities and temperatures of the storage room are plotted in Figure 1.   Similar data for the skid of commercial flour are given in Figure 2, beginning immediately upon receipt of the flour.   The data for absorption of all samples obtained on November 17, 1937, March 9, 1938, and June 2, 1938, are summarized in Table III.

Photographs of the laboratory loaves made on February 16, 1938, while the flour still retained its optimum qualities, are given in Figure 3.   Those made on June 2, after the flour had deteriorated in quality with respect to some factors, are given in Figure 4.

TABLE III

Data Showing Change in Absorption on Samples in Various Bags from November 17, 1937, to March 9, 1938, and to June 2, 1938

Sample number	Kind of bag	Date	Absorption as received, %	Absorption calculated from moisture, %	Moisture, %	Absorption on 15% moisture basis, %
1B	Paper-lined	Nov. 17, 1937	64.0		11.4	57.3
		Mar. 9, 1938	67.0	66.9	9.8	57.3
		June 2, 1938	67.0	65.1	10.8	59.1
2B	Jute	Nov. 17, 1937	64.0		11.7	57.9
		Mar. 9, 1938	67.0	68.1	9.5	56.9
		June 2, 1938	67.0	65.1	11.1	59.7
3B	Grain	Nov. 17, 1937	64.0		11.4	57.3
		Mar. 9, 1938	67.0	66.8	9.9	57.5
		June 2, 1938	67.0	64.5	11.1	59.7
4B	Cotton	Nov. 17, 1937	64.0		12.1	58.6
		Mar. 9, 1938	67.0	68.5	9.7	57.2
		June 2, 1938	67.0	66.1	11.0	59.5
5B	Grain	Nov. 17, 1937	63.0		11.8	57.1
		Mar. 9, 1938	66.5	66.7	9.8	56.8
		June 2, 1938	66.5	64.5	11.0	59.0
6B	Jute	Nov. 17, 1937	63.0		12.3	58.0
		Mar. 9, 1938	66.5	67.1	10.1	57.4
		June 2, 1938	66.5	65.6	10.9	58.8
7B	Paper-lined	Nov. 17, 1937	63.0		12.1	57.6
		Mar. 9, 1938	66.5	66.5	10.2	57.6
		June 2, 1938	66.5	65.2	10.9	58.8
8B	Cotton	Nov. 17, 1937	63.0		11.6	56.7
		Mar. 9, 1938	66.5	65.7	10.1	57.4
		June 2, 1938	66.5	64.1	11.0	59.0

Discussion

The moisture content of all the samples at the beginning of the test were normal, ranging from 11.4 to 12.3 percent. They all decreased to a minimum during the fourth month and then started increasing. At the end of the test, that is, at the end of approximately seven months, they were practically back to the moisture content at which they had started. The kind of bag had little effect on the variation in moisture content.

The percentages of ash and protein showed no significant change in any of the samples. Apparently all of the variations noted were due to experimental error. It is concluded that over the period of storage the ash and protein content of both flours in all bags remained the same, which is in agreement with the results reported by Kent-Jones (1924).

Values for absorption showed considerable variation. However, the absorption for all samples in all of the various bags showed an increase at the end of the experiment over that at the beginning. This is in harmony with the work of other investigators cited in the introduction to this paper. After about the third month, when the moisture content had reached its low point, absorptions for samples 1B in a paper-lined bag, 7B in a paper-lined bag, 3B in a grain bag, and 5B in a grain bag showed that the flour took up all of the water in mixing that it had lost as a result of evaporation. Sample 2B in a jute bag and sample 6B in a jute bag showed a decrease at this point. They did not take up all of the moisture which they had lost by evaporation. Sample 4B in a cotton bag showed this same decrease, while sample 8B in a cotton bag gave opposite results, showing an increase at this point. These data on absorption have been summarized in Table III. Absorptions on a 15% moisture basis, as well as calculated absorptions dependent upon the change in moisture and the absorption as received, are given.

The baking tests showed definitely that there was a difference in the two different flours used, yet in no case is there any significant difference in the same flour sample when stored in the various bags. The flour samples stored in the various bags with sample numbers 1B, 2B, 3B, and 4B began to show deterioration in baking quality on March 9, 1938, as is evident from the laboratory baking tests. The quality of the commercial bread containing enriching ingredients, however, held up for approximately two months longer. Infestation became evident May 6, 1938. The flour stored in the various bags with sample numbers 5B, 6B, 7B, and 8B, did not show deterioration in the laboratory baking tests until May 6. The commercial score at this date was very good. The next month the commercial score showed quite a decrease, however. The decrease in quality immediately after
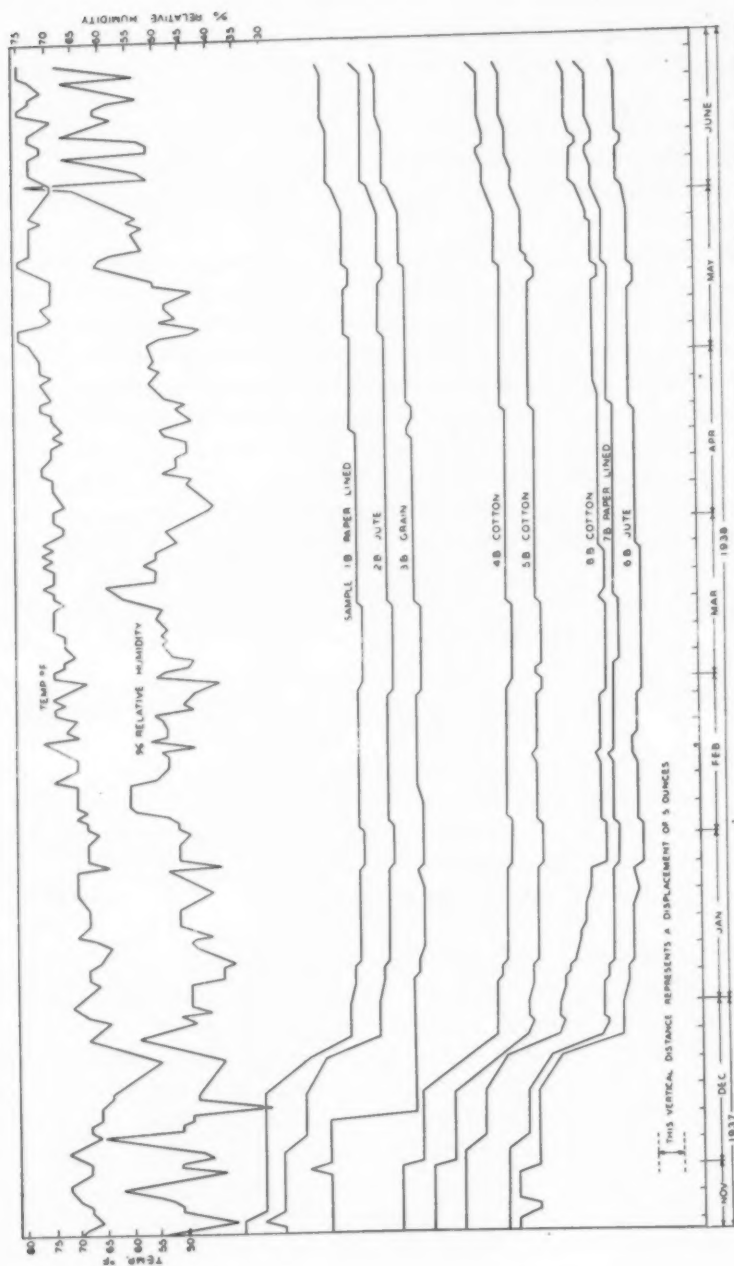
Fig. 1.   Weight changes in ounces of the various samples of flour during storage.   Changes in temperature and relative humidity of the storage room are also shown.
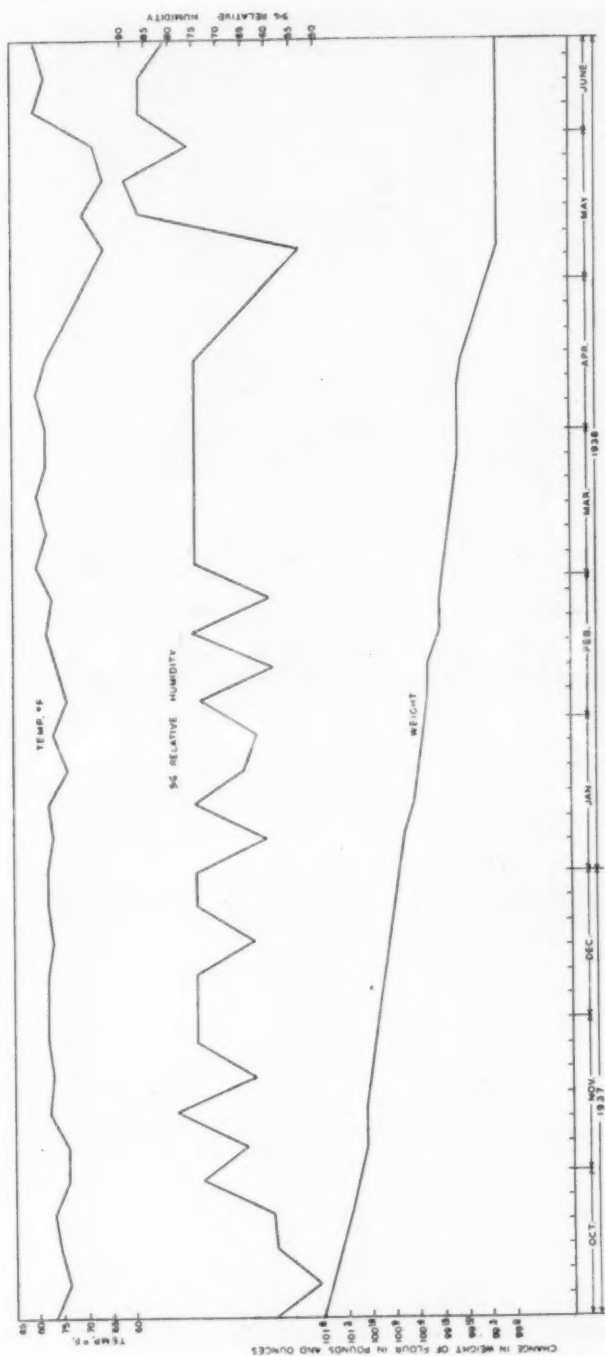
Fig. 2. Weight changes in ounces per bag of a skid of flour during storage in a bakery.   The changes in temperature and relative humidity of the storage room are also shown.
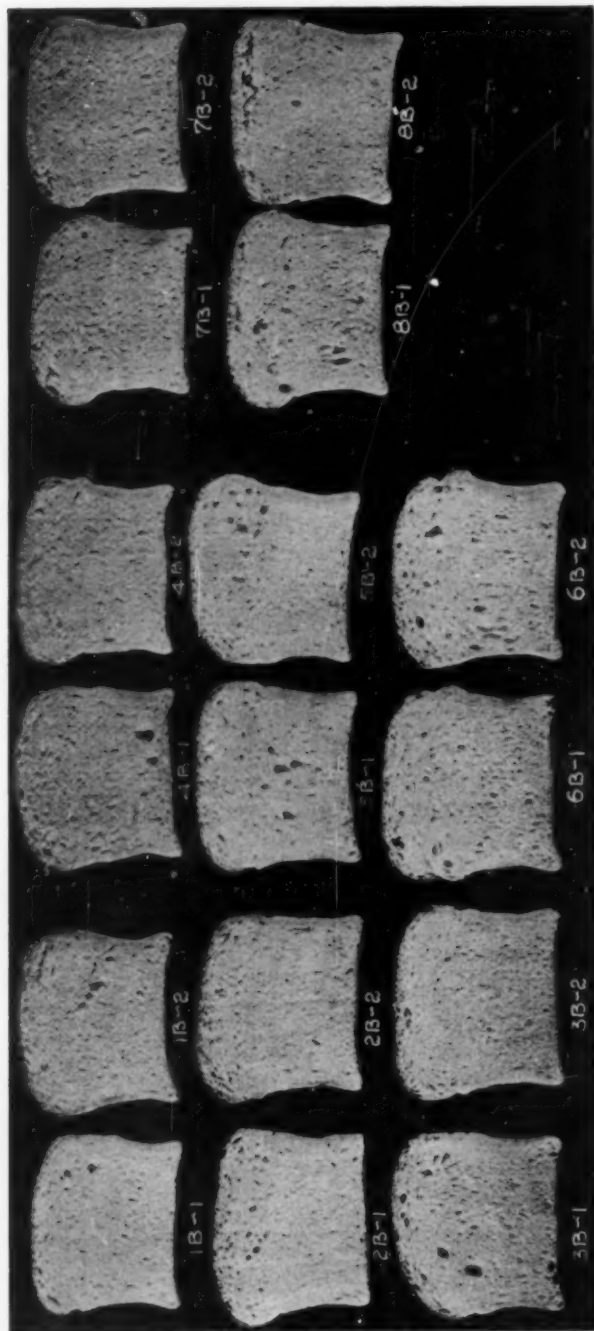
Fig. 3. Laboratory loaves made on February 16, 1938, given by sample number. The "1" following the dash represents first part of laboratory bake; the "2" represents the second part. All samples were as good on this date as at beginning of the test.
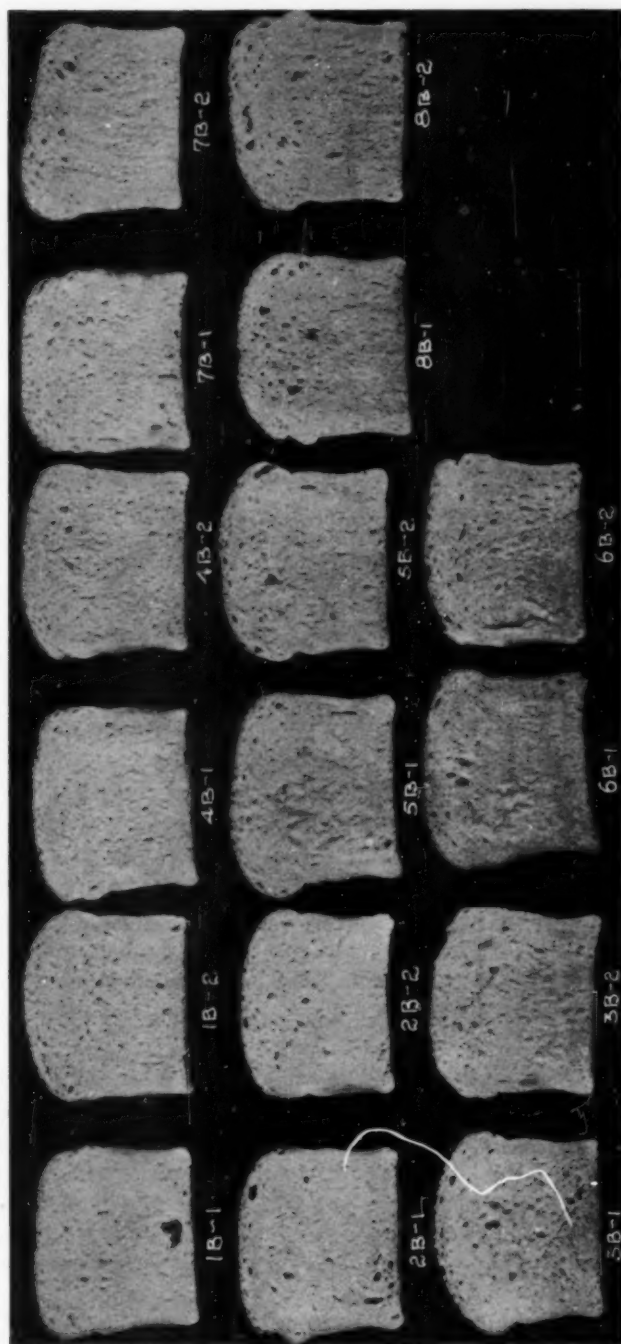
Fig. 4. Laboratory loaves made on June 2, 1938, given by sample numbers. The "1" following the dash represents first part of laboratory bake; the "2" represents the second part. Practically all characteristics shown by the photographs are as good as on February 16, 1938; however, the total] scores are lower mainly because of aroma, taste, and color.

the baking tests on May 6 is due to the fact that infestation had developed since the previous test.   Thus the baking test on June 2 is of little significance, except to show the great decrease in quality. From an examination of Table II, it is evident from the baking tests of all samples down to May 6 that there was no difference in the baking quality of each separate flour which was stored in the various bags. Although the baking tests after this show some variation, it is doubtful that this was due to the infestation.   However, the bakes on May 6 and June 2 show a slight advantage, perhaps, for the paper and cotton bags.

The fact that both flours had maximum baking quality at the beginning of the experiments and after a time showed a decrease agrees with the work of Kuhl and Kliefoth (1934).   As far as could be determined by the baking tests, the diastatic activity of the flours showed little change during storage, which is in agreement with the work of Kent-Jones (1924) and Marotta, Di Stefano and Vercillo (1935).

Photographs of all the bakes could not be given; however, the laboratory loaves made on February 16, 1938, before any of the samples showed any deteriorations, are shown in Figure 3, and the corresponding loaves made on the last test June 2, 1938, are given in Figure 4. It is evident from these pictures and the data of Table II, that the deterioration in the samples is mainly due to degradation of the aroma, taste, and color and not to the other factors of the score.

The volume on various days showed considerable variation and was quite low on January 5 in the case of the commercial samples.   The only explanation which can be given for this is the uncontrollable personal factor of the operator.   On the whole, the results are quite consistent and there is no significant difference in the volumes from the samples in the various bags.   Nearly all samples showed just about as high a volume at the end of the test as they did in the beginning.   This is especially true of the commercial loaves and is in agreement with work of Swanson, Willard, and Fitz (1915), Saunders, Nichols and Cowan (1921), and Greaves (1926).

The weights on the various bags are given in Figure 1 along with the temperature and humidity of the storage room.   The samples which were weighed contained approximately 30 lbs. of flour, and up to December 24, 1937 the bags were only weighed to the nearest quarter pound.   However, at this time the scale was changed and the bags weighed from this point on to the nearest ounce.   Thus, in examining the results it is suggested that the weights given before December 28 be disregarded.   It will be noted that the weights vary approximately the same in all bags.   All of the curves decrease to a minimum and then increase.   The curves as given are not actual weights but the varia-

tions from the first weight.   From these tests the kind of bag has little effect on the rate of moisture loss or on the rate of gain in moisture. Thus, the results do not verify Krtinsky's (1937) results that jute allows a greater rate of moisture loss than paper bags.   It will be noted from Figure 1 that there was considerable variation in temperature and humidity throughout the period of storage.

Figure 2 is of interest only for comparison.   The kind of bag used for the flour was ordinary cotton.   Although there was considerable variation in humidity and temperature during the storage period, the flour showed a gradual decrease in weight throughout the storage period.   In other words, the variation in humidity and temperature did not cause fluctuation in the weight of the flour per bag as was noted with the smaller samples.   This is what is to be expected, however, from the results of Arpin and Pecaud (1923).   On April 14, 1938 the storage room of the skid of flour was changed and for a period of approximately three weeks no records were made.

Conclusions

Of the two chemically matured and bleached flours used in this test, one held up longer during storage than the other.   Both had optimum baking qualities at the beginning of the test.   One flour did not begin to deteriorate until about the fourth month, the other flour until about the sixth month.   Deterioration in the latter sample seemed to be due mainly to insect infestation.   As far as could be determined from the analyses, there was no change in the protein or ash content of these samples during storage.   The absorption showed an increase in all cases.   The kind of bag used for storage made little difference in the results of the analyses or baking tests, with the possible exception of absorption.   In a few cases near the half-way point the flour did not regain all of the moisture which had been lost during storage.   It is hoped that the effect of the various bags on absorption can be re-studied with a more accurate measure for absorption.

Summary

Two different samples of chemically bleached and matured flour were stored separately in four different types of bags, namely ordinary cotton, paper-lined, jute, and grain.   They were stored under average commercial bake-shop conditions.   The samples were analyzed at regular intervals for moisture, ash, protein, and absorption, and baking tests were made.   The kind of bag had little effect on the analyses or the baking quality of the flour.   In all cases absorption increased during storage, ash and protein showed no change, and the baking quality in one sample fell off after the fourth month and in the other

after the sixth month.   Deterioration in the latter case was due to infestation.   The effects incidental to storage are in general agreement with the work of other investigators.

Acknowledgment

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GAS RETENTION AS AFFECTED BY INCLUDING SHORTENING IN THE TENTATIVE A.A.C.C. BASIC TEST-BAKE FORMULA [1]

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(Read at the Annual Meeting, May 1939)

In 1937 the author reported that shortening used in a straight-dough commercial formula, up to 4%, increased loaf volume slightly, with all classes of shortening tested, and that shortening lowered the height of the gas retention curve.[2]

The tests were made with a commercial formula. The baking committee decided to study the effect of shortening on gas retention, using the A.A.C.C. basic procedure. A study of this nature seemed to be desirable since some of the members using the A.A.C.C. basic procedure include shortening in their formula.

Experimental

Three extractions of bakers' flour (patent, straight, and first clear bleached and unbleached) were selected for this test. Preliminary tests were performed to determine the absorption and approximate mixing time. Two levels of shortening were used, namely 2% and 4%, imposed on the A.A.C.C. basic procedure with absorption and mixing time predetermined. From the same piece of dough on which the gas-production and gas-retention tests were made, duplicate baking tests were also made at 86° temperature for fermentation and proof, with the 3-hour fermentation as called for in the basic procedure.

Table I shows the results obtained on the three flours which were commercially bleached and diastatically treated. The first column shows that the total gas on all flours was slightly reduced by the addition of shortening. This has been verified by a number of methods other than gas retention. Under "Gas retained," we find that in the case of the patent and straight flours, the 2% and 4% of shortening definitely reduce the percent of gas retained over the 6-hour fermentation period. In the clear flour a different result is obtained. Here we find that 2% of shortening definitely increases gas retention and that 4% gives the same results as no shortening at all.

TABLE I

EFFECT OF SHORTENING ON GAS RETENTION AND ON LOAF VOLUME FOR BLEACHED FLOURS

	Rate per hour of total gas	Gas retained	Time to elastic limit	Volume
	cc./100 fl.	%	min.	cc.
PATENT (BLEACHED)				
No shortening	386	38.7	291	535
2% "	376	34.0	242	524
4% "	374	34.1	263	530
STRAIGHT (BLEACHED)				
No shortening	394	41.0	304	556
2% "	405	34.3	238	597
4% "	385	34.0	228	587
CLEAR (BLEACHED)				
No shortening	422	31.0	215	510
2% "	420	34.7	268	554
4% "	405	30.9	218	585

The upper curve (Fig. 1), representing 2% shortening, is perfectly smooth until it reaches its elastic limit. In the lower curve there is a break which definitely shows a reduction in gas retention up to a certain point, when a gradual rise in gas retained occurs. This explains why the percentage of gas retained is slightly greater in the clear flour with the shortening than with no shortening whatsoever.

We have found in some of our experiments that shortening has a tendency to mellow a slightly bucky dough. Wherever the flour has dropped on the gas-retention curve and then started to retain gas again the result was a rather bucky dough. Shortening apparently eliminates this; if not entirely it at least helps.

In the next column, "Time to elastic limit," we find that again in the patent and straight flours the time is reduced considerably to the elastic limit, but in the bleached clear flour the 2% shortening increased the time to this point. The unbleached clear also showed less time to the limit with both 2% and 4% shortening.
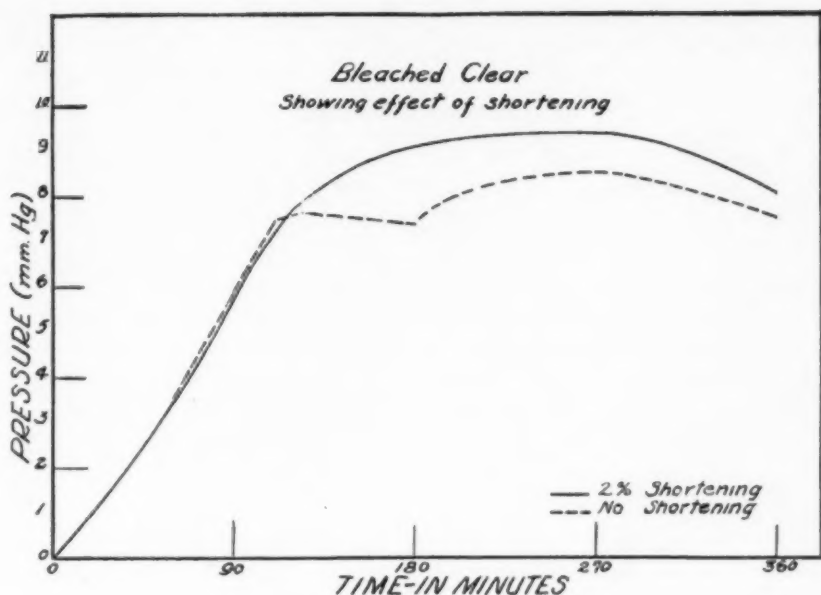
Figure 1.

In the "Volume" column it appears that the effect of shortening on volume for the patent flour was practically negligible with slight increase in volume for straight grades and clears.

Table II carries out the same idea as Table I, except that unbleached flours are used in place of bleached flours. We find that in

TABLE II

EFFECT OF SHORTENING ON GAS RETENTION AND LOAF VOLUME FOR UNBLEACHED FLOURS

	Rate per hour of total gas	Gas retained	Time to elastic limit	Volume
	cc./100 fl.	%	min.	cc.
	PATENT (UNBLEACHED)			
No shortening	400	36.4	268	562
2% "	390	32.4	217	560
4% "	364	34.8	214	573
	STRAIGHT (UNBLEACHED)			
No Shortening	375	37.1	247	539
2% "	372	31.6	184	542
4% "	360	29.1	209	562
	CLEAR (UNBLEACHED)			
No Shortening	417	28.8	235	518
2% "	387	29.5	222	551
4% "	373	29.4	199	562

general the same results are obtained as with the bleached flours, with the exception of unbleached clear.

Summary of Results

It may be concluded that with the apparatus used and with the patent and straight-grade flours, bleached and unbleached, gas retention (as determined in percent of total gas retained in the dough) was reduced by the use of shortening. While in the bleached clear flour 2% shortening had a tendency to increase gas retention, 4% shortening did not materially change the percent of gas retained over the 2%.

In all cases of patent, straight, and clear flours the total rate of gas per hour was slightly reduced. In the case of the patent and straight grades the time to the elastic limit was also reduced. In the clear bleached flour the time to the elastic limit was increased, while in the unbleached it was reduced quite materially.

It is our belief that the inclusion of shortening in the A.A.C.C. formula would tend to make the baking results more satisfactory on a flour that exhibits bucky characteristics. However, the tendency to mask this bucky effect might render the test bakes less useful. In spite of this fact and knowing that the baker uses a rather liberal amount of shortening in his formula, I would recommend 3% shortening as being a very desirable amount to use in the A.A.C.C. baking formula.

REPORT OF THE 1938–39 A.A.C.C. COMMITTEE ON STANDARDIZATION OF LABORATORY BAKING[1]

Claude F. Davis, *Chairman*

Western Star Mill Co., Salina, Kansas

(Read at the Annual Meeting, May 1939)

During the past two years the baking committee has attempted to encourage the development of test-bake equipment with the idea that some outstanding types would be acceptable for standardizing the test and that such equipment would become readily available to many laboratories and materially overcome some of the test-bake problems. Some of the problems are high experimental error in loaf volume, double breaks in oven expansion, high loaf ends, more uniformity of inside and outside loaf characteristics between replicates in the same bake, more consistent results from day to day, and the personal factor in dough manipulation.

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[1] General report.

With these problems more nearly under control we would be in better position to determine flour characteristics as shown by the basic and all supplementary treatments within and between different laboratories. With the complex system dealt with in test baking one cannot be surprised at the rather high experimental error that persists in spite of all precautions. If this error could be compared favorably with the variability in such tests as bacterial or bacterial-spore counts in flour, within or between laboratories, we would probably be better satisfied with the present baking-test results.

The greater the experimental error in any test result, the less chance we have of differentiating between the subjects under test or between the imposed test treatments. Replication of tests leads to an average which approaches the actual value. When differences between the subjects under test or responses to certain treatments are of high magnitude, then the baking test is a safe basis of evaluation in any one laboratory or even between laboratories as shown recently in collaborative studies conducted by J. M. Doty of the Nebraska Section, in which unanimous agreement was reached on the evaluation of four wheat varieties. Collaborative tests conducted recently by L. E. Leatherock of the Pioneer Section Research Committee on different Kansas wheat varieties showed a high degree of agreement between laboratories. In these cases the differences in the flour characteristics were rather pronounced.

Wheat selections, milling operations, and flour evaluations often demand a differentiation between samples that show less difference than in the above-mentioned collaborative studies. To arrive at the proper evaluation of samples in such work the experimental error must be kept at a minimum. Mechanization of many of the test-bake operations, especially dough mixing, punching, and sheeting, should, from a logical standpoint, eliminate much of the personal factor. A complete automatic sheeting and molding device should find its place in the test but experienced operators maintain that the opportunity to feel the dough at certain stages of the operations is desirable for estimating the dough characteristics. A fermented dough passed through the sheeting rolls is generally considered to be in good condition to be judged by the sense of feel. In the absence of mechanical means that can be readily, economically, and reliably utilized for measuring the fermented dough characteristics which we must know, we cannot eliminate completely the personal equation from the test. When we have progressed in our development of test-bake equipment to the point of recommending one type of mixer, one type of sheeter, and one type of baking pan we will be in position to rewrite the standard procedure for the baking test and study seriously the possibilities of

standardization by means of collaborative studies which have not been attempted since Harrel (1929) found a definite lack of consistent results between laboratories. His findings were discouraging to the extent that it has since been deemed inadvisable to expose this important test to the possibility of such a variable record of collaborative results.

With equipment standardized and handling methods definitely prescribed we should establish through collaborative study the degree of concordance and variability of results that the grain, milling, and flour trade and research and control organizations can expect between well controlled laboratories. Such knowledge will enable them to know to what extent they can rely on the test-bake evaluations to carry on their inter-related operations, and they should be fully aware that sound interpretations cannot go beyond the accuracy of the test results as ordinarily obtained. In the rewriting of the A.A.C.C. baking-test method we will have to consider the procedure with reference to the specific objectives of the test and we will possibly want to establish the basic straight-dough test as an all-round safe procedure, including such items as shortening in the formula, high sugar level, and proofing the dough to constant height as suggested by Sandstedt and Blish (1939). W. L. Heald (1939) has recommended 3% shortening as desirable for the basic formula. Landis and Frey (1936) have given estimates of adequate sugar levels to assure fermentation. With such a basic procedure supplementary tests may be applied to give responses that have greater meaning in our test-bake interpretations.

At this time I wish to summarize the recent progress in development of test-bake equipment that is pertinent to the standardization program:

The Hobart-Swanson attachment mixer which was approved by the baking committee and which has been obsolete for some time has again been made available in a slightly modified form to facilitate better mixing of 100 g. and 200 g. of flour. This mixer is now available, with its own motive power, as the National-Swanson mixer, or the modified bowl can be supplied to give the improved smaller-dough mixing effect with the old-type Hobart-Swanson attachment. Unfortunately this development came too late for this year's committee to furnish any reports on its use.

Since the last convention 18 National sheeters have been purchased by laboratories and put into use. Two papers on the use of this equipment are presented on today's program. A summary of replies to a questionaire sent to most of the users of the machine on points associated with handling doughs through the sheeter supplied the following information:

Thirteen of the sheeters are motor driven, five are hand driven. Twelve use the sheeter for punching; four do not. Ten remove the dough from the fermentation jar by hand; five use a spatula. Six use dusting flour; nine do not. The roll-sheeter setting for punching (average of nine) was 8/32″ and the range 10/32″ to 6/32″. The roll setting for sheeting (average of fourteen) was 6/32″ and the range 10/32″ to 4/32″. Eight mold the dough tight; six mold loose; one uses a special procedure. Fourteen favored recommendation of the National sheeter as approved equipment for the Tentative A.A.C.C. Baking Test; two were not definitely in favor; one was noncommittal.

There were no important suggestions for improvement in the machine. Favorable comments on the sheeter were: It is a definite work saver. It definitely tends to improve the grain and texture of the loaf. The price is not prohibitive. Unfavorable comments were: It possibly does not reduce significantly the individual's variability. In the case of soft wheat it possibly does not help and may hinder the differentiation between flours. General comments were: Loaf age marks are critical to the degree of mechanical treatment and this makes very careful standardization of procedure necessary. It does not solve the test-bake problems—it is only a step in the right direction. It should be developed with a molder. Molding by hand and machine are not significantly different; the molder is not essential.

No committee efforts have been given to oven development; however, attention should be called to such improvements as the compartment rotating hearth described by Finney and Barmore (1939) and the compartment reel-type oven developed by the National Manufacturing Co., Lincoln, Nebraska.

Recommendations

That the National-Swanson dough mixer be studied as a replacement for the Hobart-Swanson attachment—this investigation to include a comparison of the double planetary two-pin bowl and the single planetary three-pin bowl mixers.

That the power-driven National sheeter or a sheeter of the same roll size and adjustments and approximate speed be tentatively approved for the A.A.C.C. bread-baking test.

That a baking pan of the following dimensions be studied as a single-pan replacement for the two types of pans now in use and as a pan size suited to the loaf volume range of from 550 cc. to 750 cc.: 75 mm. × 115 mm. top dimension, 60 mm. × 100 mm. bottom dimension, 60 mm. deep.

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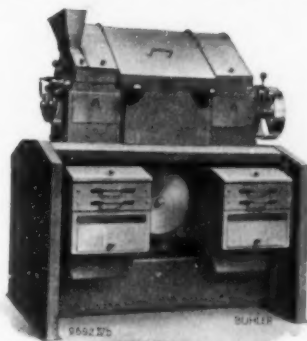Wichita Flour Mills Co., Wichita, Kans.

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